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ABSTRACT

This paper, intended for instructors and students in undergraduate courses in geography and environmental studies, discusses the significance of energy to our life and our life-styles. The document is designed to be used in a variety of ways--as background reading for a mini-conference on energy legislation and the geographic problems that are involved; as a substitute for the traditional text material; as an example of differing methodological approaches to the topic; or as required outside reading. There are five parts. Part I discusses the solar energy base of life, concepts of efficiency in agriculture, and the role of livestock. Part II treats renewable and nonrenewable resources, depletion and estimation of reserves, coal and nuclear fuels, solar energy, water power, biomass fuels, wind power, and geothermal energy. The benefits and costs of energy use are examined in Part III. Part IV discusses energy conservation and distribution and the politics involved. An annotated listing of sources of statistical information is provided in Part V. A bibliography citing resources relevant to each part is also included. (Author/RM)

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ENERGY: THE ULTIMATE RESOURCE?

Earl Cook
Texas A & M University

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FOREWORD

In 1968, the Commission on College Geography of the Association of American Geographers published its first Resource Paper, *Theories of Urban Location*, by Brian J. L. Berry. In 1974, coinciding with the termination of NSF funding for the Commission, Resource Paper number 28 appeared, *The Underdevelopment and Modernization of the Third World*, by Anthony R. deSouza and Philip W. Porter. Of the many CCG activities, the Resource Papers Series became an effective means for permitting both teachers and students to keep abreast of developments in the field.

Because of the popularity and usefulness of the Resource Papers, the AAG applied for and received a two-year grant from NSF to continue to produce Resource Papers and to put the series on a self-supporting basis. The 1977 Series is the first group produced entirely with AAG funding.

In an effort to increase the utility of these papers, the Resource Papers Panel has attempted to be particularly sensitive to the currency of materials for undergraduate geography courses and to the writing style of these papers. The present Panel continues to affirm the original purposes of the Series, which are quoted below:

> The Resource Papers have been developed as expository documents for the use of both the student and the instructor. They are experimental in that they are designed to supplement existing texts and to fill a gap between significant research in American geography and readily accessible materials. The papers are concerned with important concepts or topics in modern geography and focus on one of three general themes: geographic theory; policy implications; or contemporary social relevance. They are designed to complement a variety of undergraduate college geography courses at the introductory and advanced level.

The Resource Papers are developed, printed, and distributed under the auspices of the Association of American Geographers. The ideas presented in these papers do not imply endorsement by the AAG.

Many individuals have assisted in producing these Resource Papers, and we wish to acknowledge those who assisted the Panel in reviewing the authors' prospectuses, in reading and commenting on the various drafts, and in making helpful suggestions. The Panel also acknowledges the perceptive suggestions and editorial assistance of Jane F. Castner of the AAG Central Office.

Salvatore J. Natoli
Educational Affairs Director
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Project Director and Editor, Resource Papers Series

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John F. Lounsbury, Arizona State University
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SUGGESTIONS FOR CLASS USE

Until recently introductory geography textbooks relegated the topic of energy to a chapter or two on the distribution of fossil fuels. In this Resource Paper Dr. Earl Cook writes, "Energy is the most important physical element of what geographers call the man-environment system."

Today energy is a byword in our daily lives, yet our behavior in perceiving energy supplies or in using them appears to have changed only minimally despite the recent crisis periods of fuel shortages.

Cook illustrates that energy permeates every aspect of the man-environment system. In his introduction he writes "[energy] is a geographic subject, requiring the actual or ascribed abilities of geographers to synthesize relevant information for modeling man-environment relations."

Instructors and students in undergraduate courses in geography and environmental studies will find this paper extremely useful in a variety of contexts and most specifically in those studies that attempt to understand the special obligation of human beings to and their stewardship of the earth and its resources. This paper will raise many questions, should generate discussion, and even promote some controversy, but it should enhance our appreciation of the significance of energy to our life and to our life-styles.

The Panel on Resource Papers would hope that teachers of lower division undergraduate courses in geography would find innovative ways to use this paper—as background reading for a mini-conference on energy legislation and the geographic problems that are involved, as a substitute for the traditional text material or as an example of differing methodological approaches to the topic, or simply as required outside reading. Many colleges and universities offer short courses, weekend courses, or continuing education programs. This Resource Paper would be an excellent and inexpensive text around which to organize a course on the environmental significance of the energy problem.

Chapter V in this paper should be of particular value. It contains an annotated list of sources of energy statistics and data. The problem of seeking such data and interpreting the many ways that government organizations, special interest groups, and other data collecting agencies report energy statistics has been one of the greatest deterrents to our full understanding of the energy problem. Both faculty and students should find this chapter of extreme importance to their research.

Finally, laypersons can learn more about the complexity of the energy problem, thereby adding depth to understanding their behavior toward the use of energy—the ultimate resource.

Salvatore J. Natoli
Editor, Resource Papers Series

PREFACE

What is energy?

To the North American factory or office worker, energy is gasoline and electricity, natural gas and coal—what makes machines go, propels vehicles, heats buildings, powers blast furnaces, illuminates the television screen and the student's desk.

To the Portuguese fisherman, energy is the surge of the sea, the force of the wind, the pounding of the surf, and what he must have in his arms and back.

To the Mexican *campesino,* energy is the power in a horse, a tractor, or a truck, the burning heat of the sun, and the renewal of strength that he finds in maize and tequila.

Energy is all of these and at the same time a scientific concept that even the thermodynamicist finds difficulty in defining. The scientist may define energy as the ability to do work, but then must admit that heat energy at ambient temperature, the ultimate fate of all energy, can do no work. The engineer may speak of consuming and conserving energy, but knows that in the fundamental sense neither of these verbs is accurate, for energy cannot be consumed, only degraded, and cannot be conserved for reuse, only well used while being degraded.

Ecce homo: the great degrader of energy, whose cultural ascent is the story of an increasing control of energy flows and stocks, whose population expansion has been subsidized by the aggressive and ingenious exploitation of the fossil fuels, whose future is clouded by the environmental and social consequences of that exploitation.

Energy supplies, in forms useful to society, are very unevenly distributed throughout this world. Some nations have abundant arable land; some have little. Some have great rivers whose flows can provide hydroelectricity; some have few. Some have immense pools of petroleum; some have none.

The true wealth of the world is in such energy supplies. It is not in gold, but in productive land; not in myrrh and frankincense, diamonds and dollars but in falling water, crude oil, natural gas, and coal.

Finding and exploiting the natural subsidy of such energy resources has enabled the human species to acquire knowledge and power at a rapidly increasing rate, to double or triple the life span of individuals, and to conceive means of production, communication, and transport that were inconceivable only a short while ago.

The distribution of the benefits of energy-resource exploitation, however, has been as uneven as the original geographic distribution of the resources themselves. In fact, there has been a clear tendency for energy wealth, translated into industrial and thus economic power, to pull energy out of less industrialized communities and nations. Petroleum is the obvious example, but the anchovies of Peru and the beef of Argentina are others. The consequences are apparent, not only in striking disparities of diet and income among nations (in some places within nations), but also in divergent views of energy problems and crises.

In the United States, a temporary shortage of gasoline in 1974 was seen as a crisis, while at the same time many of the world's people faced a much harsher and a two-horned energy crisis—a shortage of food energy from indigenous sources and a shortage of fuel from foreign sources, the first because land productivity was not keeping pace with population growth, the second because they couldn't afford the new prices dictated by the oil cartel.

The overwhelming problem faced by *industrial* man is that of converting from nonrenewable sources of energy to renewable sources, from dependence upon finite stocks to utilization of dependable flows, with minimal social disruption and life-style degradation. This conversion may prove impossible, especially for the so-called advanced countries.

The pervasive problem faced by *nonindustrial* man is survival. It has been said that industrial man is the more endangered by depletion of energy stocks and that nonindustrial man, who is supported by energy flows, is the probable survivor. This

statement relates to cultural levels, not to numbers. In regard to numbers, non-industrial man faces perhaps the graver threats, for one must not forget that biologic resources when overharvested because of hunger or mistreated out of ignorance also are depletable even to exhaustion.

Industrialization, the traditional focus of economic development, requires a large surplus of food, beyond that required by the tillers themselves. Such surplus has been achieved where inanimate energy, cheaply acquired in terms of human labor, has been available to replace the muscular energy of humans and draft animals.

When less than fifteen percent of the work force can produce, process, and distribute the food required by the other eighty-five percent, as is the case in the United States, or where the products of efficient factories can be traded for imported food, as in early industrial England, and later industrial Japan, there is an enormous subsidy of human enterprise by inanimate energy supplies which allows most of the people to devote themselves to producing goods and services, in other words, to economic development. Everywhere, economic development has been based mainly on the exploitation of fossil fuels, whether indigenous or imported. Even Sweden, with its abundant hydropower, gets half its energy from imported oil.

The process of development is reversible, because it depends on stocks rather than flows of energy. Development becomes more difficult where food production is insufficient to support the large fraction of the work force that must be devoted to industrialization. It may be that, as inanimate energy grows more expensive and food production approaches physical limits, the entire concept of economic development will need to be altered radically, and that the stage of development of a nation will come to be judged more by social indicators that stress psychic income than by pecuniary indicators that stress material accumulation.

Energy is the most important physical element of what geographers call the man-environment system. The analysis of energy in the context of this system and the search for practicable answers to human problems involving energy cannot be carried out adequately within such restricted frames as those of traditional economics, or of thermodynamic engineering, or of social or political management. This is a geographic subject, requiring the actual or ascribed abilities of geographers to synthesize relevant information for modeling man-environment relations.

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CONTENTS

SUGGESTIONS FOR CLASS USE v
PREFACE vii
I. ENERGY, LIFE, AND FOOD 1
The Solar-Energy Basis of Life 1
Concepts of Efficiency in Agriculture 1
The Role of Livestock in Food-Energy Conversion 3
II. ENERGY FLOWS AND STOCKS 4
Renewable and Nonrenewable Resources 4
Depletion and the Estimation of Reserves 5
Coal and the Nuclear Fuels 6
Solar Energy 7
Water Power 7
Biomass Fuels 8
Wind Power 8
Geothermal Energy 8
III. BENEFITS AND COSTS OF ENERGY USE 9
Benefits 9
Costs 10
Problems of Replacing Oil and Gas by Coal and Uranium 11
Energy Affluence and Energy Scarcity as Social Hazards 13
IV. ENERGY DISTRIBUTION, CONSERVATION, AND POLITICS 14
Uneven Distribution and Use of Energy Resources 14
Not One World, but Four 17
The American Energy Economy 17
Conserving Energy 18
Where Energy Could Be Conserved in the United States 19
The Politics of Energy 21
V. SOURCES OF STATISTICAL INFORMATION 24
BIBLIOGRAPHY 28

LIST OF FIGURES

1. Food Energy Flow of a Tsembaga Community in New Guinea 2
2. Flow of Digestible Food and Feed Energy in the United States, 1972 3
3. Logical Framework for the Exploitation-History Method of Depletion Forecasting 6
4. International Oil Flows, 1976 16
5. Flow of Energy Through the U.S. Economy, 1976 18
6. Energy-System Efficiency of the American Automobile 20
7. Efficiencies of Energy Use in the United States, 1800-1972 21

LIST OF TABLES

1. Energy Flows in Rice Culture 2
2. Conversion Efficiencies of Food Animals in the United States, 1972 3
3. Flows and Stocks of Energy, a Classification 4
4. Energy Use in the World by Source, 1975 5
5. World Stocks of Energy, 1975 7
6. Comparison of Electricity Systems Associated with a 1,000-Megawatt Power Plant 11
7. Arable Land, Main Countries, 1970 14
8. Daily Per Capita Food Supply in kcal for Selected Countries, 1970 14
9. World Coal Reserves, Major Countries, 1966 15
10. Reserves and Daily Production of Crude Oil and Natural Gas, Major Countries 15
11. Per Capita Daily Energy Consumption in Selected Countries, 1974 17
12. Distribution of Total U.S. Energy Consumpton by End Uses, 1975 19

I. ENERGY, LIFE, AND FOOD

The Solar-Energy Basis of Life

The energy that supports life on this planet comes from the sun. Were the umbilical cord to solar radiation to be severed, there would be no life. Plants are the key to life, for only they can use solar energy for growth and reproduction, through the vital process of photosynthesis. No animal, including man, knows how to do this. Plants combine water and carbon dioxide to produce the carbohydrates, lipids, and proteins of cellular tissue. Plants do not need animals, because the water on earth comes from degassing of the planet and is distributed by the hydrologic cycle, whereas most of the carbon dioxide comes from the decomposition of dead plants. But animals need plants, not only for food and fiber, but for the life-supporting oxygen that plants give off as a waste product.

Life on land is possible because of the hydrologic cycle, which is driven by solar energy. Great masses of water ceaselessly are being evaporated from the oceans and moved by the global wind system over the land, where some of the water falls as rain, supporting the growth and reproduction of plants, succoring animals, and keeping alive the rivers and lakes that we use for transport, power production, and as sources of food.

Solar radiation provides the light without which there would be perpetual night, and it provides ambient heat in the relatively narrow temperature range within which life as we know it can exist.

We may take all this as evident and hardly worth repeating, especially if our perceived energy concerns deal more with the high cost of fuels, a growing dependence on imported oil, and the Faustian prospects of nuclear power. For the longer-term welfare of human communities, however, there are certain conclusions to be drawn from such a simple restatement of the obvious. First, that we may run some desperate risks if we do not pay attention to the conditions under which plants, especially trees, can be maintained in adequate quantity on the earth. Second, that our attempts to improve the natural efficiency of plant growth and to increase the benefits we derive from the hydrologic cycle should be calculated to perpetuate energy flows and to avoid the unwitting conversion of naturally renewable flows of plant food and falling water into depletable resources through soil erosion, siltation, and other consequences of poor management. Third, that food is the most important form of energy, at least of those that humans manage, and, therefore, that the maintenance of food-plant productivity should be the primary goal of energy management.

Photosynthesis is an inefficient way to convert solar energy into food, but it's the only way we have. A principal objective of agriculture has been to maximize yield, that is, the areal efficiency of photosynthesis in terms of digestible food (for humans) or feed (for livestock). We have been able to do this by selecting or breeding plants that concentrate a large part of their chemical energy in the parts that humans and animals eat (as in the kernels of maize) or in the parts they can digest (as in the juice of sugarcane); by using fertilizers and water to promote growth; by weeding and applying herbicides to eliminate useless competitor plants; by campaigns to reduce or eliminate plant diseases, pests, and predators; by irrigating in accordance with the changing water needs of the cultivated plant during its growth cycle. All such efforts require energy in excess of that supplied by the sun, and thereby invoke the concept of efficiency, a very anthropocentric notion that encourages attempts to measure the ratio of useful output to directed or managed input and thereby to compare the effectiveness of processes designed to increase human well-being. Because efficiency is such an important analytical tool in energy studies, it will be useful to look at it first in the context agriculture, where all its facets and multiple definitions can be examined.

Concepts of Efficiency in Agriculture

There are at least five kinds of efficiency represented in agriculture.

The efficiency that American farmers are apt to boast about is based on the ratio of production to farm labor. Less than five percent of the U.S. work force is on the farm. The U.S. has achieved world records in food and feed production per man-hour of farm labor. The total food production and distribution system, however, requires more than twice as many man-hours as does agriculture itself, especially if one factors in the five to ten billion man-hours expended each year by American consumers in grocery shopping and transport.

Another kind of efficiency in agriculture is based on production per acre or hectare. With all its great mechanical skill, available machines, a chemical arsenal against pests, and massive inputs of fertilizers, America's mechanized agriculture isn't all that far ahead of hand agriculture in crop yields. Indeed, given similar soil, climate, and crop varieties, intensive hand agriculture sometimes can outproduce mechanized agriculture. However, rapid advances in crop breeding and management, coupled with intensive use of fertilizers and pesticides, have created impressive gains (fifty percent or more) in production per hectare in North America during the past twenty years, and it is not clear that these advances can be adapted to hand agriculture.

A third kind of efficiency is energetic. Mechanized

agriculture is subsidized by energy from outside the system. If we look only at plant crops, not livestock, there is still an energy gain at the farmgate, but with livestock included there is a loss. When we examine the entire food production and distribution system of the United States, we see that eight to ten units of fossil energy are required for each unit of food energy reaching American kitchens. It is this fossil-energy subsidy that allowed Great Britain, Germany, the United States, and other countries to industrialize, by drastically reducing the number of workers in agriculture and by moving the surplus labor into industry, commerce, and transportation. Without cheap fossil fuel, the astounding social and economic resurrection of Japan from the ashes of World War II and its reemergence as a world power could not have occurred. Hand agriculture is much more energy efficient than mechanized agriculture. The contrast is illustrated by the calculations of Gary Heichel (1973), who has shown that rice grown and harvested by hand labor in the Philippines yields 17.3 units of digestible energy for each unit of energy invested, whereas rice grown and harvested in Louisiana with the aid of machines yields only 1.4 units of digestible energy for each unit invested (Table 1). Heichel's calculations illustrate what is called energy accounting; even items usually expressed in dollars are converted (from studies of the processes involved) into energy units. In his two examples, Heichel had divided total

TABLE 1. ENERGY FLOWS IN RICE CULTURE

(all units are thousands of kilocalories[1] per acre)

Item	Philippines (1970)	Louisiana (1970)
Energy Input		
Human labor	36	2
Animal labor	82	0
Fuel	0	1,760
Other variable costs[2]	0	1,095
Fixed costs[3]	0	1,392
Total input		
Seasonal	118	4,249
Annual	331	11,936
Energy Yield		
Digestible (food) energy		
Seasonal	2,035	5,969
Annual	5,716	16,766
All (food and fuel) energy[4]		
Seasonal	5,032	12,643
Annual	14,115	35,514
Digestible Energy Yield/Energy Input	*17.3*	*1.4*
Yield per acre (kg)	1,360	3,417

[1] A kilocalorie (kcal), the "calorie" of nutritionists, is the energy required to raise the temperature of a kilogram of water by 1°C.
[2] Seed, fertilizer, lime, feed, repairs, etc.
[3] Equipment depreciation, taxes, insurance, interest, etc.
[4] Rice straw and chaff, if used as fuel, would yield more energy than the grain.
Source: Heichel, 1973: 25.

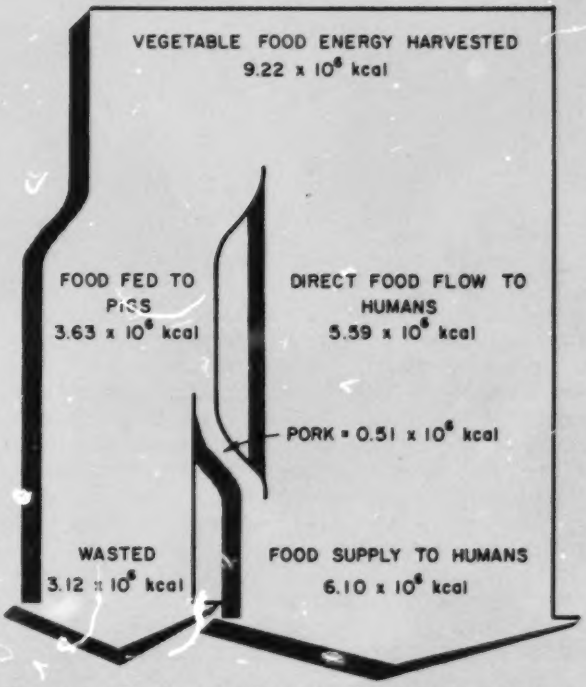
VEGETABLE FOOD ENERGY HARVESTED
9.22 x 10⁶ kcal
FOOD FED TO PIGS
3.63 x 10⁶ kcal
DIRECT FOOD FLOW TO HUMANS
5.59 x 10⁶ kcal
PORK = 0.51 x 10⁶ kcal
WASTED
3.12 x 10⁶ kcal
FOOD SUPPLY TO HUMANS
6.10 x 10⁶ kcal

Figure 1. Food energy flow of a Tsembaga community in New Guinea. Based on information in Rappaport, 1971: 121. The conversion efficiency of the system is sixty-six percent. The human-labor input is 560,000 kilocalories; the food-energy return on that investment is about eleven times.

energy inputs by the number of acres harvested in order to compare the two systems.

A fourth kind of efficiency is economic, as measured in money. In a market economy, decisions on what to plant, how much to plant, the kinds and amounts of agricultural chemicals to apply, and what management systems and machines to use, are based on the anticipation of profit, in other words, on economic efficiency. The needs of this nation or other nations for food, the desirability of conserving petroleum products, the threat of lowered productivity far in the future because of slack attention to soil-nutrient conservation today, potential damage to the lives or property of others from the unwise use of agricultural chemicals—all these enter into farmers' decisions only insofar as they are reflected in prices, and in government regulations and incentive or support programs. In the Soviet Union, the largest factor of uncertainty in crop forecasts is the climate; in the United States, it is the farmer.

A fifth kind of efficiency that enters into all human activities, including agriculture, is that of social efficiency. Social efficiency might be defined as the degree to which, for an individual or a community, psychic income is maximized. Psychic income is a general term for happiness, pleasure, the sense of dignity, the pride of position, the love of place, all of which, in varying mixture, can make life worth living. For many people in this world, fear of the future is the greatest detractor from happiness. Such fear comes from uncertainty about the means of obtaining food, clothing, and shel-

ter, and of coping with the threats of disease and oppression. To have a job that pays a living wage, or an occupation that yields subsistence, is a goal of millions. In countries with high unemployment and underemployment, and which are constrained in their industrial development by lack of resources or capital (which is almost the same thing), it may be more socially efficient to have twenty workers in a field, all producing enough for themselves and their dependents to live on, than to have two workers and a machine in that same field. Even though the latter could produce food more cheaply in money terms, the social costs of maintaining the eighteen displaced and unhappy workers may outweigh the pecuniary gain from the machine.

The Role of Livestock in Food-Energy Conversion

Before abandoning food (as a subject), let us look at still one more kind of efficiency, the efficiency of conversion of the digestible energy in harvested and grazed plants into human food.

In the New Guinea community of the Tsembaga studied by Rappaport (1971), the digestible energy harvested

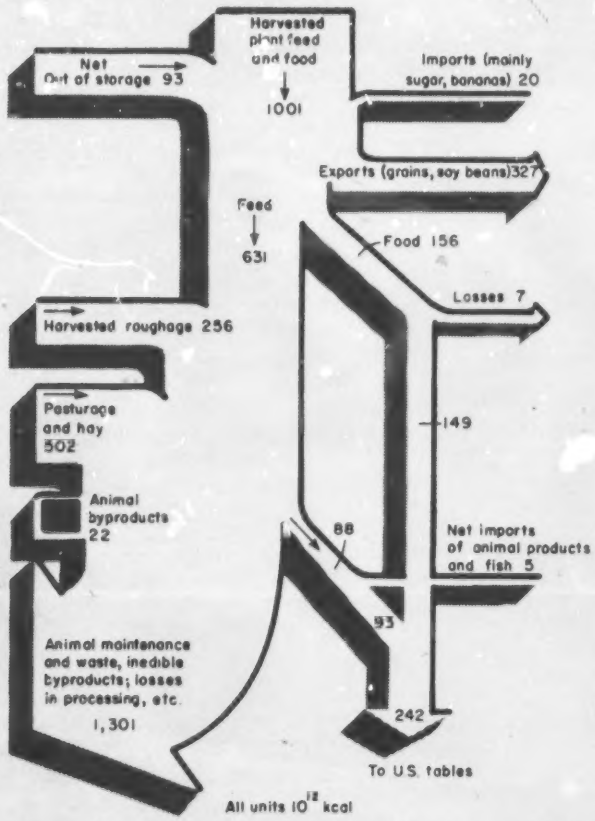

Figure 2. Flow of digestible food and feed energy in the United States, 1972. All units are trillions of kilocalories. The energy in feed eaten by animals other than people and pigs is equated to the digestible energy in human food through use of the Corn-equivalent Feed Unit, developed by the U.S. Department of Agriculture in order to compare the utility of different feeds in different animals.

TABLE 2. CONVERSION EFFICIENCIES OF FOOD ANIMALS IN THE UNITED STATES, 1972*

	Energy	Protein
Milk cattle	14.6	20.5
Hogs	10.0	11.6
Chickens (meat and eggs)	7.3	20.4
Turkeys	7.2	17.8
Beef cows	2.9	5.2
Sheep and goats	1.6	3.6
Average for all livestock	6.3	10.6

* System efficiencies, from plant feed to retail product, based on feed-disappearance and food-production data of the U.S. Department of Agriculture for 1972, adjusted to food-supply data by calculations of diversions in butchering and marketing.

(Figure 1) totaled 9.22 million (10^9) kilocalories, of which 3.63 million went to pig food, and 5.59 million went directly to human food. The total output in vegetables and pork was 6.10 million kilocalories. The conversion efficiency thus was sixty-six percent; in other words, about two-thirds of the energy in the plant food harvested got to the consumer, as a mixture of vegetables and meat. Rappaport emphasizes in his study that Tsembaga pig culture is rigorously constrained by convention; if it were not, the leisure time of the tribe, which is the "profit" from the effort they invest in raising food, would be traded quickly for unnecessary pork. The energy ratio of human effort expended (560,000 kcal) to food gained was one to eleven in the Tsembaga example.

Now let us turn to an agriculture entirely different in methods and scale, that of the United States. In 1972, the overall conversion efficiency was 15.3 percent; 1,759 trillion (10^{12}) kilocalories were harvested and grazed; net exports and storage changes reduced that total to 1,545 trillion, which went into domestic feed and food (Figure 2); the output was 149 trillion kilocalories of plant food and eighty-eight trillion of edible animal products. The total food supply included five trillion kilocalories of imported animal products and fish. The 242 trillion kilocalories delivered to U.S. tables represented about 3,200 kcal per day per person; because of the large livestock component in the American food system, more than 20,000 kcal of plant energy were required to produce the daily per capita diet. The energy-conversion efficiencies of the major food animals in 1972 ranged from 1.6 to 14.6 percent (Table 2).

Of the total digestible energy harvested (not including grazed forage) and used within the United States, eighty-seven percent was fed to livestock. This may seem an inefficient way to use arable land, but it's pleasant for those who like meat, milk, and eggs. Present crop and grazing land in the United States could support 1.2 billion people on a nutritionally adequate diet, one that would still include more meat than most of the world's people can afford.

A fact that tends to be obscured by production and yield increases is that the basic productivity of American soil is related to the fossil-energy subsidy inversely, not directly. The inherent productivity of the soil probably has been decreasing at the same time yields were increas-

ing, because of soil-nutrient loss through erosion stimulated by mechanized tillage, by monoculture, and by the large scale of agricultural operations. Not only might similar yields be obtained from the same land by intensive hand agriculture, but soil losses surely would be less. Production is a one-time thing; productivity is a longtime thing. What is subsidized and maintained by fossil-fuel energy is the small number of workers on the land. If the fuel subsidy ceases to exist, because first North America and then the world run out of crude oil (and natural gas, from which all ammonia fertilizer used in the United States is made) and because we can find no adequate substitute for motor fuel, we will need more workers on the farm for the same production. The miracle of American agriculture, like industrial development in general, is reversible.

II. ENERGY FLOWS AND STOCKS

Renewable and Nonrenewable Resources

Energy is found in flows, as solar radiation, and in stocks, as pools of crude oil and beds of coal (Table 3). The distinction, although not quite as sharp on examination as at first blush, is a useful one. Perhaps renewable and nonrenewable are more apt words, however, because the distinction and its utility hinge on our perception of time.

Geologists are reasonably certain that deposits of oil and coal are forming now, at favorable sites within the shallower parts of the earth's crust. It would take so long, however, probably hundreds of thousands of years, to generate even as much oil or coal as the world burns in a single day, that for all intents and purposes, these are nonrenewable resources whose economically exploitable deposits constitute stocks of finite extent. The same is true of natural gas and of the nuclear fuels, uranium and thorium. Even geothermal energy, as it has so far been exploited, is nonrenewable, for the geothermal energy sources in Italy, Iceland, Japan, and California, that have proven exploitable are finite deposits of heat and water trapped by relatively impermeable geologic formations.

TABLE 3. FLOWS AND STOCKS OF ENERGY, A CLASSIFICATION

Flow (renewable):
Solar radiation
Water power, for mills
Wind power
Tidal power
Geothermal energy (heat flow)
Food
Fuel wood, including charcoal
Other plant fuel (alcohol from sugarcane and manioc; bagasse, corn cobs)
Dung and other animal wastes
Stock (nonrenewable):
Fossil hydrocarbons
Crude oil
Natural gas and natural-gas liquids
Coal, lignite, peat
Tar sands
Nuclear fuels*
Uranium
Thorium
Water power, for electricity generation
Geothermal energy (in heat traps)

* The fuel for fusion reactors, if they prove feasible, will be deuterium, of which there is an extremely large supply in sea water. However, lithium, a metal of more limited occurrence, may also be needed.

The only continuous unidirectional energy flow that has been tapped by man is the falling water of rivers. Solar, tidal, and wind energy are intermittent flows, of which solar and tidal have the advantage of being periodic. Solar energy has been used for heating, cooling, drying, and to a very limited extent, for the production of electricity.

Food, wood, and other vegetable fuels are renewable, but as flows they are intermittent, requiring transient stocks to be accumulated before we can use them. Except for the channeled energy of rivers, most natural energy flows are diffuse and require substantial energy investments for concentration to usable intensities or storage of useful quantities.

During the past two centuries, the industrialized world has greatly enlarged its population, raised its level of living, and structured its built environment as well as its life-style on the use of energy from stocks, from the nonrenewable fossil fuels. In the United States eighty-eight percent of the energy consumed (including food and feed) comes from the fossil fuels. In the world (Table 4), the fossil-fuel total is seventy-eight percent. These percentages are based on gross consumption of energy resources, such as coal and grass; they do not include secondary forms of energy such as electricity produced through the burning of coal or meat produced through the eating of grass.

The limit to the use of a *renewable* energy resource is a *rate*, the maximum rate at which the basic flow can be exploited. The limiting rate may be the rate of the natural flow, as with sunlight and rivers, or it may be the maximum rate at which transient stocks can be maintained, as is the case with soil fertility and marine food resources. A renewable resource can be depleted toward exhaustion by overharvesting, but good stewardship would guard against that. The limit to the use of a

nonrenewable resource is a *quantity*, the total that can be found and used economically. A nonrenewable resource will be depleted by any exploitation, and exhaustion can be avoided only by halting exploitation. Because the forecasting of stocks of oil and gas has been recognized, somewhat tardily, as a matter of grave importance to modern society, we turn now to the concept of depletion as applied to reserves and "resources" of finite stocks of energy.

Depletion and the Estimation of Reserves

The limit to the use of a nonrenewable energy resource is a quantity, determined either by the cost level at which a substitute becomes acceptable or by the point at which it takes as much energy to find, transport, and process the energy material into usable form as can be gotten from it; at the latter point there are no more reserves, proved or "potential," no matter how much of the material may remain in the ground.

Depletion is the physical diminution of the ultimate supply of a nonrenewable resource. Depletion begins with the first ton of coal mined, the first barrel of oil pumped, the first cubic foot of gas burned. Just as a human being starts running out of life as soon as he or she is born, so an oil field or a coal bed starts being depleted as soon as extraction begins. The human will gain size and strength during the first years of life; so will the oil field or mine gain in proved reserves. In each case there will come a peak, after which a decline will set in. In some cases the decline is precipitous; in most it is gradual. Exhaustion of an oil field or mine may be delayed by improved technology of extraction or by increasing prices for the product; but such delays, which represent increases in the amount of material that can be extracted economically, are generally modest because geophysical constraints on production tend to be so severe that very large increases in price are required to extend reserves significantly.

It is difficult to calculate reserves of oil and gas, mainly because we can't see through rock. Scientists calculate reserves from information obtained from drill holes, information on hydrocarbon content and composition, on porosity and permeability, on thickness of the producing "horizon," and on its susceptibility to stimulation of hydrocarbon flow by fracturing, chemical dissolution, gas or water "drive," and other techniques. They recalculate these reserves each year and there can be substantial changes from year to year, not only because of withdrawal of oil and gas but also because of altered judgments on the factors mentioned above as additional drilling yields more relevant information. In one recent year, the figure for "additions to reserves" of natural gas in Texas was a large negative; downward corrections of prior estimates more than overbalanced new discoveries.

M. King Hubbert (1956, 1962, 1969) has demonstrated an evolutionary pattern in the relations among discoveries, reserves, and production of oil and gas, and he has postulated the following (see Figure 3):

(A) *The amount ultimately produced will be equal to or less than the amount initially present.* To date, of all the crude oil discovered in the United States (oil-in-place estimated from drill hole data), only slightly more than a fourth has been produced and it appears highly unlikely that more than forty percent will ever be brought to the surface. Crude oil tends to cling tenaciously to the rock of its reservoir. Some oil will flow freely to a well. Some will move to a well under the pressure of injected water or gas. But to recover as much as half of the oil in most reservoirs will require techniques that are expensive in both money and energy. Recovery of natural gas from most of its reservoirs is much easier. It is common to recover eighty percent of the gas in a natural gas reservoir, because gas is much less viscous and doesn't have the affinity for solid surfaces that oil has.

TABLE 4. ENERGY USE IN THE WORLD BY SOURCE, 1975

Source	Percent of Total	
Crude oil	35	79% nonrenewable
Coal	26	
Natural gas	17	
Uranium	1	
Plant food and feed	9	21% renewable
Dried dung	5	
Wood and vegetable refuse	5	
Falling water	2	

Source: Cook, 1976: 226.

(B) *Production will begin at zero and end at zero.* All oil wells, all gas wells, and all mines are exhausted eventually. Production starts some time after discovery, rises to one or more peaks, and may be extended by new discoveries, by more efficient extraction techniques, and by higher prices that allow exploitation of more recalcitrant deposits. But eventually the end comes. As it is with a single well, so it is with a field. And as it is with a field, so it will be for a province and finally the world. The peak of U.S. oil production occurred in 1970; the peak for the world is now estimated to occur in the early 1990s.

(C) *There will be a consistent time relation among the three variables of cumulative discoveries, cumulative production, and proved reserves.* In the United States, the time interval (Δt) between the curves of cumulative discoveries and cumulative production of crude oil has been about eleven years; when the rate of discovery (dQ_p/dt) peaked, about 1956, it was thus possible to predict that the rate of production (dQ_p/dt) would reach its peak about 1968; actually, it occurred two years later, a difference attributable to the difficulty of determining the actual peak of the discovery curve (discoveries vary greatly from year to year).

(D) *Rates of change of these three variables may be derived from formulas fitted to the curves of the exploitation record for any region, nation, or the world.* From the production-rate curve (dQ_p/dt) one may then forecast the depletion of the resource in question.

The production-history method of estimating undiscovered, recoverable energy resources cannot be used for regions of little or no production, such as the North Slope of Alaska. The principal competing method is that

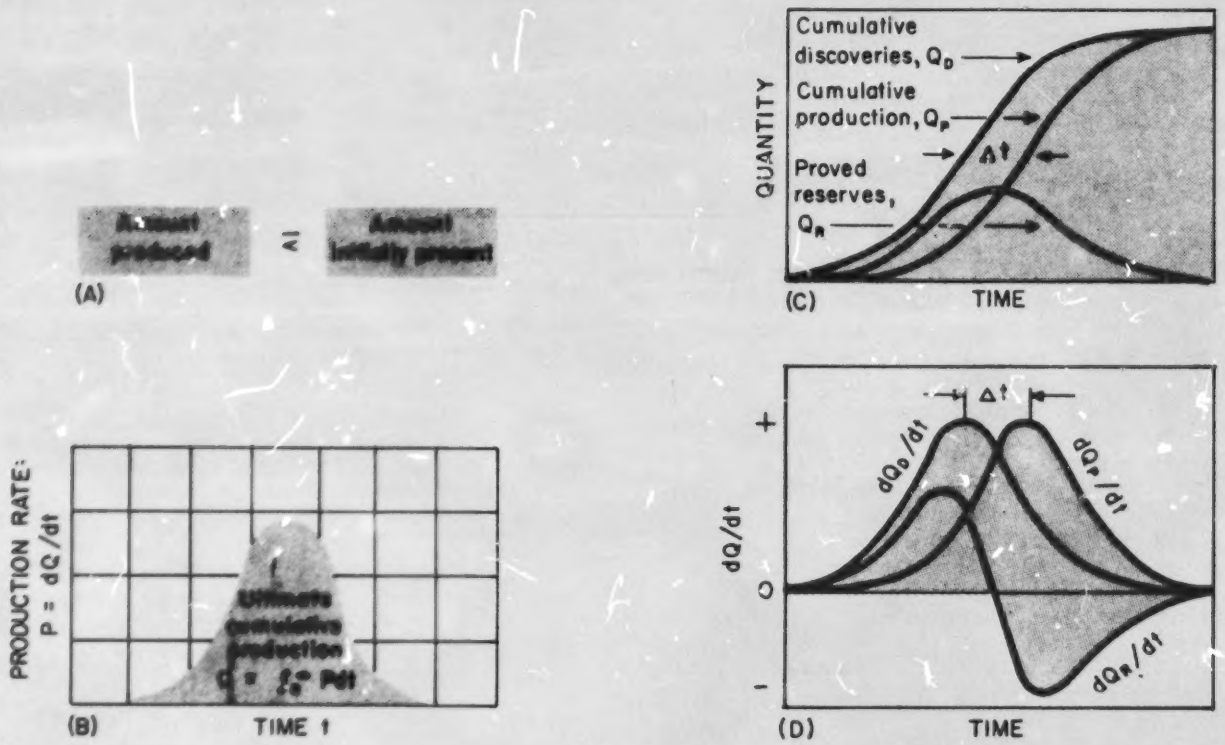

Figure 3. The logical framework for the exploitation-history method of depletion forecasting has four links: (A) the amount ultimately produced will be equal to or less than the amount initially present; (B) production will begin at zero and end at zero; (C) there will be a consistent time relation among the three variables of cumulative discoveries, cumulative production, and proved reserves; so that (D) rates of change in these variables may be derived from formulas fitted to the curves of the actual exploitation record. From the production rate curve (dQ_P/dt) one can then forecast the depletion of the resource in question. (From Hubbert, 1956, 1962, 1969).

which invokes geologic analogy, comparing, on the basis of geologic parameters (as many as thirty are used by some practitioners), the potential energy-resource content of unexplored areas and geologic formations with the known content of well-explored areas and formations. The U.S. Geological Survey has refined this method, as have some major oil companies, and recent estimates, put in probability format, from the Geological Survey and from the Exxon Company, USA, of the remaining crude oil and natural gas potential of the United States are in substantial agreement with those of Dr. Hubbert, arrived at by a different method.

The Geological Survey as well as other government agencies are inclined to present estimates of potential reserves or "resources," as they call them, in a graphic format, using the concept of "the resource base," which can be very misleading to the uninitiated. The resource base is defined as all of the desired material that may be present and either actually or potentially recoverable economically. To the optimist, this may mean all the oil, gas, uranium, or geothermal heat in the earth's crust from the surface down to an arbitrary limit representing the optimist's expectation of future advances in drilling and extractive technologies, and of future increases in the market price of the commodity in question. Such a presentation leads the viewer to what may be (and surely is, for oil and gas) a highly erroneous conclusion, that present proved reserves are but a small fraction of what ultimately will be found and recovered (Cook, 1975b).

Coal and the Nuclear Fuels

What are the alternatives to oil and gas? Let's look at what we know about the remaining stocks of coal and the nuclear fuels. Granted there are difficulties in estimating reserves in areas of substantial production and free information flow and these are compounded when one attempts to estimate them for areas of little or no production and for areas where governments restrict the flow of such information. The figures in Table 5 as presented are reasonable global estimates for "reasonably assured" and "probably discoverable" reserves or "resources." Nuclear-fuel resources surely are understated in this tabulation, because we know so little about them in large parts of the continental world such as the Soviet Union and China. Two conclusions strike the reader forcibly: (1) the coal resources of the world are fourteen times greater than the remaining oil and gas combined, and (2) the nuclear-fuel resources will equal or exceed the coal resources if we adopt breeder reactors in place of the present inefficient "burner" reactors.

It would appear, from resource-stock estimates alone,

that the industrial world can continue to exist, and possibly to expand, by substituting coal and the nuclear fuels for oil and gas as the latter run out. There are, however, additional costs, some economic and calculable, some environmental and partially calculable, some social and incalculable, that may make the substitution difficult. These will be addressed in the next chapter.

Solar Energy

The economics of solar energy used for heating, cooling, and drying are so different from the economics of electricity produced from solar energy that a sharp distinction must be made between the two. In many parts of the world solar heating and drying are economic now. In industrialized countries such as the United States, solar comfort-conditioning, assisted by heat pumps, could, within thirty years, provide twenty-five percent of the nation's energy supply, most of which fraction now comes from natural gas and fuel oil. What is needed is not a technological breakthrough but the economics of mass production and large-scale installation, which can be obtained by government incentive programs and revision of restrictive building codes.

Conversion of solar energy to electricity, on the other hand, is, with existing materials and technology, very much more expensive than available alternatives for electricity generation. The prospect of clean, renewable power unconstrained by the threats of exhaustion and political interdiction, however, has created much enthusiasm and optimism. At present, the cost of delivered electricity (mainly from thermal power plants) in the United States ranges from three to ten cents per kilowatt-hour (the average to the residential consumer in 1975 was 3.21 cents, according to the Edison Electrical Institute). Solar-thermal power systems, which convert sunlight to heat and the heat to electricity by means of a heat engine such as a steam turbine, can produce electricity at a cost of about $4 per kilowatt-hour. The capital cost of the solar system is said to be about $4 per peak watt (Hammond, 1977a), which is about four times more than for a contemporary nuclear plant and about ten times more than for a coal-fired plant.

A recent (1977) report issued by the congressional Office of Technology Assessment (OTA) claims that solar devices capable of producing electricity for less than $1/kwh could be available in the next few years. One is reminded of similar optimistic predictions in the 1950s about the future cheapness of nuclear power. However, there may be two significant differences between the economics of solar and nuclear power: first, the economies of large size in solar plants are not as great as in nuclear plants (where the cost of a unit of power produced decreases with increasing size of the plant), and, second, there is an intriguing possibility of building small- to medium-scale solar plants for both heating and power in which the cost of the electricity could be reduced significantly below that produced from a single-purpose solar power plant (Duguay, 1977; Metz, 1977a). The potential range of solar systems in kind and size, which would allow them to meet a wide range of need in less industrialized or sparsely inhabited areas while providing an alternative to scarce fossil fuels in industrialized regions, is another element in the flame of hope that illuminates research and development in solar energy.

TABLE 5. WORLD STOCKS OF ENERGY, 1975

Resources	Without Breeder Reactors		With Breeder Reactors	
	*	(% of Total)	*	(% of Total)
Crude oil	2.1	3.1	2.1	1.7
Natural gas	2.1	3.1	2.1	1.7
Shale oil	4.0	5.9	4.0	3.2
Tar-sand oil	1.7	2.5	1.7	1.4
Coal	57.1	84.7	57.1	45.8
Uranium	0.4	0.6	42.5	34.1
Thorium	0.0	0.0	>15.3	12.3+
	67.4	99.9	>124.8	100.3

* Units are 10^{18} kcal.

Source: Cook, 1976: 260. Based on totals of "reasonably assured" and "probably discoverable" resources as given in Brobst and Pratt, 1973.

Water Power

An early phase of the Industrial Revolution was based on the energy of falling water, used to propel water wheels that turned mills along all the rivers of western Europe, mills that ground grain, fulled cloth, sawed wood, polished marble, crushed ore, turned grindstones, prepared the mash for beer, and, in short, did much of the mechanical work now done by electric motors. This was true renewable power, because the dams and reservoirs required were small enough to be cleared of accumulated sediment when necessary.

Hydroelectric power generally is classified as renewable energy, but it isn't. All large reservoirs eventually will fill with silt and become useless for power development or water storage, unless we can find ways to remove the silt economically. In a clean river, the reservoir impounded by a dam may last four hundred years; in a dirty one, perhaps as little as fifty years. Hydropower is clean, relatively inexpensive, and enormously attractive to countries without fossil fuels. But, with present technology, it is a nonrenewable resource. In some countries, merely building a dam increases the siltation rate in a river. In Costa Rica, for example, the road built into a watershed to carry construction materials to the Cachí dam encouraged logging upstream from the dam that resulted in increased erosion and even landslides into the filled reservoir. For countries such as Costa Rica, which has no fossil fuels, methods of controlling siltation must be found. For all countries that have developed hydroelectric power, an economic method of desilting reservoirs would be a great boon.

In the United States, water power produces about fourteen percent of the electricity generated. That percentage is unlikely to increase, because the remaining good sites for high dams for the most part are preempted for other uses. Undeveloped hydropower poten-

tial is mainly in Latin America and Africa where it is of great importance because of the general lack of coal and the spotty distribution of oil and gas fields.

Biomass Fuels

At one time all fuel used in the world was grown. Fuel wood or charcoal made from wood was used for both comfort heating and process heat—for making glass, ceramic, and metal objects. In the industrializing world coal gradually replaced wood and later crude oil and natural gas largely replaced coal. In the non-industrialized parts of the world firewood, dried dung, and vegetable refuse such as bagasse, remain major fuels. Wood fuel is in theory renewable, but where it has been overharvested to the stage of severe soil erosion or desertification it is no longer renewable on a time scale meaningful to present generations or to their grandchildren. Recently, the concept of fuel plantations has been given a boost with the decision of Brazil to produce up to twenty precent of its motor fuel from sugarcane and cassava or manioc. It seems possible that the kind of farming that would be most sustainable in the vast Amazon basin might be that of quick-growing trees for the production of liquid and solid fuels.

Great areas of land would be required to produce, through plants, any substantial portion of the fuel used by modern societies. Where use of that land for fuel plantations competes with its use for food production, food production eventually will take precedence (unless world population, through some catastrophe, commences to decrease, thus relieving the pressure on arable and semiarable lands). In some countries, forests remain capable of producing substantial fuel wood; Sweden during World War II derived most of its fuel from wood. In other countries, forests have been overharvested for fuel, cut back to provide land for crops, or both.

Apart from the growing of plants to produce fuels, interest in what are called biomass fuels is concentrated on the possibilities for utilizing waste materials: agricultural field and processing wastes, spoiled or low-quality grain, wastes from timber cutting and wood-products manufacture, municipal wastes (garbage), animal excrement, and economic waste such as sugarcane when the price of sugar falls below the cost of producing it. A walnut factory in California can produce gas from walnut shells sufficient to supply all its energy needs at a cost half that of the natural gas alternative (Hammond, 1977b). Not all biomass energy is that favorable economically; the ethanol produced in Brazil from sugarcane, for example, will cost three to four times the cost of gasoline made from imported crude oil, on an energy-equivalent basis; in that case, there are strategic (a renewable, domestic source), social (new jobs), and even economic (reduction of the sugar oversupply that has driven world prices down) advantages that overbalance the high cost.

Propagation of aquatic plants such as algae and water hyacinths as feedstock for methane production has been proposed. The champion plant in the production of dry biomass remains sugarcane with recorded yields approaching fifty tons per acre per year.

Wind Power

Wind power has been used in many parts of the world (windmills appear to have been invented in Persia), primarily to lift water and to propel ships. Windmills and sailing ships in commerce have been replaced largely by motor-driven mills and vessels because the latter are faster, more dependable, and can be built in larger sizes. Windmills can be built to store energy, as water in an elevated tank, as compressed air, or as electricity in batteries, for use in periods when the wind is not blowing, and there is considerable interest in windmills as appropriate for relatively light use in areas where electricity is either unavailable or expensive. Small windmills of modern, efficient design are in use in Andean regions, both for pumping water and for compressing air to run small machines.

The capital cost of large wind turbines produced in quantity is expected to be somewhere between $7 and $15 per watt of capacity, which is very high, but a study by the U.S. Bureau of Reclamation of an especially attractive site near Medicine Bow, Wyoming, suggests that a field of wind turbines there could produce electricity at a cost of two cents per kilowatt-hour, far below even optimistic estimates for solar electricity (Metz, 1977b). In many regions the wind energy available annually is nearly as large as the energy in solar radiation reaching the earth. Such energy is much more concentrated, and wind turbines are much more efficient than direct solar systems in converting the natural energy flux to electricity. Wind power systems easily achieve thirty-five percent efficiency, whereas the best solar systems are but fifteen percent efficient. The problem of storing energy during periods when the wind doesn't blow can be solved either by running the wind system in conjunction with a hydroelectric system, holding back the dammed water when the wind is blowing, or by producing compressed air and storing it in underground reservoirs as natural gas is stored in many parts of the world.

Geothermal Energy

If we could devise a means of using the very large amounts of heat that exist in the continental crust at a depth of less than ten km, we would have a source of energy of major importance. Hot dry rock geothermal energy as an economic system depends upon a positive answer to the question: Can a significant rate of induced heat flow (at a temperature of 150° C or higher) be obtained from a hot dry rock mass at an energy "profit?" In other words, will the energy needed to fracture the hot rock and to circulate a heat-transfer fluid, probably water, through the fractured rock, be less or more than the useful energy obtained? The basic problem is the low thermal conductivity of rock, which is an insulator rather than a conductor of heat. A large, well-planned, and well-executed demonstration project will be needed to determine the answer.

In the meantime, exploration and development con-

tinue in regions of recent volcanic activity where hot water and steam have been trapped by relatively impermeable geologic formations near enough to the earth's surface to be exploited economically. Geothermal power plants exist in Italy, Iceland, Japan, the United States, New Zealand, the Soviet Union, and El Salvador. Geothermal water has been used for space heating in several parts of the world (in Boise, Idaho, and Klamath Falls, Oregon, for many years) and potential uses of hot water issuing from geothermal power plants are receiving some attention. In the coastal region of Texas and Louisiana, deep wells drilled for oil and gas have encountered abundant hot water in which methane (natural gas) is dissolved. Research is under way in an attempt to develop a system to produce electricity, recover the gas, and use the effluent water for agricultural or other purposes. The concept of drilling into magma (molten rock) to recover geothermal energy appears likely to be tested in Hawaii. At the present stage of technoiogic development, it is not possible to estimate accurately the size of the potential contribution of geothermal energy to national or world needs.

III. BENEFITS AND COSTS OF ENERGY USE

Benefits

In low-energy societies, the benefits of energy use are discussed more than the costs, whereas the opposite is true of high-energy societies. A low-energy society is one in which the per capita daily energy consumption, including food and feed, is less than 50,000 kcal (Mexico = 30,500; Brazil = 17,000; Indonesia = 4,800).* A high-energy society is one in which the per capita daily energy consumption, including food and feed, is more than 50,000 kcal (USA = 235,000; Sweden = 118,000; USSR = 99,000)*.

No one who has come recently, after dark and in good weather, upon an ancient city such as Cuzco, Peru or Dubrovnik, Yugoslavia, to find it sparkling with electric lights and projecting its halo on the velvet night, can have failed to wonder, however briefly, at the almost incredible changes electricity has brought to human life. Nor can one who has traveled to such a city swiftly by jet and gone about its streets comfortably by car fail to marvel at the power enjoyed by the average person in a high-energy society, power which kings of a few generations ago would have envied.

Perhaps in no aspect of modern life, however, is the contrast with the past as significant as in the field of health.

The ingenious use of inanimate energy has stimulated and financed enormous advances in public health and medicine. As stated earlier, an abundance of cheap energy, mainly from the fossil fuels, allowed the emergence of industrial and technological society (Cottrell, 1955; Hubbert, 1962, 1972). In such societies, although most of the energy surplus has gone into machines and structures, some of it has been allocated to improving the health and working conditions of laborers so that they would be more productive when coupled to machines. Part has been used to improve the health and longevity of consumers, thus allowing consumption to keep pace with growth in productive ability, and part has been devoted to mass education, allowing the range of desire and ability in the society to expand to meet the needs of industrial growth.

The great advances in medicine and public health have been made within the past 350 years (starting with William Harvey's famous essay in 1628 and the introduction of quinine into Europe in 1632), mainly within those countries that led the way in the application of inanimate energy to industrial processes—England, Germany, Austria, France, and the United States. At any time since 1650, a map of significant events in the history of medicine and public health would have been also a map of high-energy society, that in which per capita energy use was substantially above the world average and drawing away from it.

We tend to forget that only about fifty years ago the fear of epidemic shadowed all minds and that disease, not the Colt 45, was the great leveler of America's frontier age (Shryock, 1960). The environment then was hostile; one was chary of proffered drinking water, fearful of insect bites, concerned about cuts and scratches, and alert to the hazards of contagion. And nobody spoke of a "right" to a healthy and clean environment.

The growth of high-energy society—however bad its consequences for certain groups of laborers (Engels, 1892), especially for the children and women economically drafted into mines and textile mills and for men bound like slaves to their employers—brought great improvements in general health conditions (Buer, 1926; Sigerist, 1943). Through the early years of the nineteenth century it was common for persons to sleep in their clothes and highly uncommon to take baths (Flinn, 1965; Reynolds, 1946). No city in America had either a sewage system or a piped-water system at the turn of that century, and Benjamin Rush, a Philadelphia physician, complained of the stench from the privies of his city (Corner, 1948). In the northern states, families spent much of the winter packed together in the one heated room of the dwelling, which had its windows and doors sealed tightly to prevent loss of heat. Winter food was nutritionally poor; refrigerated transport of fruits, vegetables, and meats (involving new uses of inanimate en-

* All figures refer to 1972; fuel wood and energy from wastes not included.

ergy) did not begin until after the Civil War. Under such conditions, contagion could spread easily. Even in hospitals it was common to find two or more patients, related only by disease, sharing a bed.

As affluence—generated largely from energy "profits" from the use of sailing ships, falling water, and firewood—began to spread through the northeast states, this scene changed. People began to heat more than one room of the house, and even to install bathtubs. The introduction of cheap soap (McLaughlin, 1971) and cheap textiles for clothing probably advanced public health more than any single subsequent breakthrough in knowledge of disease vectors. Malaria and yellow fever, both of which had been scourges of the northeast in colonial and early national days, retreated southward during the first decades of the nineteenth century, long before much was known about the provenance and propagation of either disease.

In the second half of the nineteenth century, a greatly enlarged energy subsidy, now coming mainly from coal through the use of steam power, financed a substantial improvement in national nutrition as well as the widespread introduction of municipal water and sewage systems. Home heating systems became less costly and more efficient. As the benefits of surplus energy spread throughout the American society, uncleanliness and infestation no longer were regarded as "natural" attributes of the lower classes, but as signs of turpitude.

In the twentieth century, the buildup of a chemical arsenal against the microscopic terrors of disease has shifted the balance of mortality causes in high-energy society away from the diseases that struck all ages and might be epidemic toward those that afflict mainly the elderly and are not contagious (Morison, 1973). The great advances in chemotherapy, as well as in mechanical means of prolonging life, could have been made only in a society with surplus energy to spend in research, development, and specialized education. One of the striking differences between low-energy and high-energy societies is in the associated levels of health-care delivery.

Costs

The development of high-energy society, however, has had its costs. The direct environmental impacts of intensive energy use have been given much attention (SCEP, 1970; Schurr, 1972), and significant steps have been taken to ameliorate air and water pollution and to preserve selected areas in a quasi-natural state. Public concern has been focused on birds killed by oil spills, fields destroyed by strip mining, people choked on petrochemical smog, fish and wildlife killed by pesticides, caribou fenced in by pipelines, the danger of nuclear-reactor meltdowns, and the somatic hazards of lead, zinc, and ionizing radiation in the biosphere. Each of these unwelcome events or processes, however, has either a known preventive or remedial treatment; none reflects a risk of killing millions of people or of lowering their level of living permanently.

The environmental and social costs of exploiting the fossil fuels are well-known (Cook, 1978), whereas those of the nuclear fuels have been extensively debated. There are even such costs related to hydroelectric dams, and to solar and geothermal power plants, but they are small compared to those of the fossil and nuclear fuels.

It seems clear that indirect or hidden impacts of energy use may be much more dangerous to mankind than are tanker spills or strip-mining (Holdren and Ehrlich, 1974; Woodwell, 1970). Some examples may serve to make the point.

Most important, perhaps, are the imbalances high-energy society has created in food supply, and the pressure on world food supplies that has come about because of the lowering of mortality rates in many countries without corresponding declines in birth rates. Many, if not most, people in high-energy society are overfed in relation to the exercise they get, and poorly fed as well (Pyke, 1968). Many, if not most, people in low-energy societies are underfed for the work they do, and are likewise poorly fed because their diet is deficient in protein (Borgstrom, 1969). Both the calorie and the protein deficiencies of low-energy societies are to a great extent consequences of the growth of high-energy society. The medical and public-health technologies of high-energy societies have been exported to low-energy societies, greatly reducing their death rates, especially among the young, causing their populations to grow and to press against available food supplies; attempts to increase food production through exported agricultural technology have been less successful, the Green Revolution notwithstanding, and the prospect of mass starvation in one or more parts of the world is real (Hendricks, 1969). High-energy society, furthermore, drains protein away from the regions where it is needed for human nutrition and feeds much of it to animals. Even in high-energy society there are disturbing signs in the health field. The incidence of cancer of the colon is increasing rapidly in the United States. From studies in several countries, it appears that this is one of a set of diseases of affluence. The fact that life expectancy for adults in the United States has increased only slightly (especially slowly for men) during decades when life expectancy at birth has increased substantially suggests strongly that high-energy life-style, diet, environment, or some combination of these three factors, has effectively counteracted the medical and public-health advances of the past half-century (Leaf, 1973).

Convergence of two other effects of high-energy society could cause a drastic decline in world food production. These effects are, first, the increasing tendency toward monoculture, the extensive growing of a single variety of food plant bred for productivity, and, second, the extension of the climatic changes now being induced near urban and industrial centers by the release of waste heat energy, and more widely by the large-scale introduction into the world atmosphere of carbon dioxide, water vapor, and fine particulate matter from the burning of fossil fuels. The former produces "heat islands;" the latter increases cloudiness and can either increase or decrease the surface temperature over large portions of the earth.

Climate appears to respond significantly to small changes in atmospheric transmittance, surface albedo,

and vertical temperature distribution in the atmosphere (Bryson, 1974). Highly inbred food plants may not be able to resist a pestilential onslaught unleashed by a small climatological perturbation. The Irish potato famine, it should be recalled, resulted from a succession of two cool, wet years that triggered the explosive growth of a devastating fungus (Dubos, 1959).

Problems of Replacing Oil and Gas by Coal and Uranium

Crude oil and natural gas not only are versatile fuels and easy to transport but they have minor environmental and social costs compared to their most likely substitutes, coal and uranium (Table 6). More than half the coal produced in the United States each year comes from strip mines, mainly in the West; this ratio is likely to persist, because much of the nation's low sulfur coal, in demand because of air pollution standards, lies at shallow depths in Montana, North Dakota, Wyoming, New Mexico, and Texas. Underground mining of these deposits is not feasible and if it were, would be much more expensive. It is not certain that strip-mined land in semiarid to arid regions can be rehabilitated; it is certain that, where the coal seam is thick, the land cannot be restored to its original elevation, although the new federal strip-mining law requires restoration to the approximate original "contour." There is understandable concern in the West for the integrity of aquifers that may be affected by surface mining. But in general, strip-mining, no matter how ugly it may look to a nonminer, is more conservative of the resource (eighty percent or more of the coal may be recovered for use compared to an average of about fifty-seven percent for underground mines) and much safer and more healthy for the workers than underground mining. In addition, the long-term environmental impacts of underground coal-mining (mine fires, acid mine drainage, and surface subsidence) can be worse than those of strip-mining properly carried out.

It is from the burning of the coal that the most serious environmental impacts come. Besides the addition of carbon dioxide to the atmosphere and heat to the environment, common to the burning of all fossil and vegetal fuels, oxides of sulfur and nitrogen, fly ash, and significant amounts of mercury and uranium are generated in burning coal. Not all of this material can be trapped in the stack by precipitators and scrubbers, although most of it can.

The ultimate answer to the environmental and health problems of both strip- and underground coal-mining, as well as to the problem of noxious [illegible] pollutants, may be *in situ* (in the place where the coal is located) gasification, a process worked on for [illegible] years in both Europe and America, which now appears to be nearing economic feasibility. In this process, a controlled fire ignited through bore holes produces a gas consisting largely of carbon monoxide and methane which is drawn out of the ground through other drilled wells. This gas can be used for industrial processes, including electricity generation, at the site of the *in situ* operation, or it can be upgraded in energy content by hydrogenation to be shipped as substitute natural gas through pipelines to distant points of use. Gasification will allow the removal of ash, sulfur, and other deleterious natural constituents of the coal before the gas is burned. If a high-energy gas similar to natural gas is the end product, it appears unlikely that more than fifty percent of the energy in the coal in place will remain in the clean gas, but that is almost as good as the present recovery efficiency for underground mining, which has a great many more environmental debits than does gasification. If a low-energy gas is the end product, *in situ* gasification should be able to exceed the recovery efficiency of deep coal mines. *In situ* gasification can be applied to oil shale as well as to coal, and it may turn out to be the only way to exploit the low-grade oil shales that occur in such

TABLE 6. COMPARISON OF ELECTRICITY SYSTEMS ASSOCIATED WITH A 1,000-MEGAWATT POWER PLANT

		Annual environmental impacts[2]			
		Occupational			
Fuel	System Efficiency[1]	Deaths	Injuries	Solid Waste, tons[3]	Waste into Air, tons[3]
Coal, deep-mined	31.3	4.00	112.3	1,559,000	71,504
Coal, surface-mined	31.3	2.64	41.2	4,219,000	71,504
Oil	29.8	0.35	32.3	213	43,079
Natural gas	31.8	0.20	18.3	0	24,057
Uranium (in LWR[4])	15.2	0.15	5.4	2,620,000	6,192

[1] Percent of the available energy in the fuel when extracted from the earth, represented by the electricity produced. For uranium, only the energy in the fissile isotope ^{235}U is assumed; if the energy in the fertile isotope ^{238}U were included, the conversion efficiency of the LWR would be dismal, less than two-tenths of a percent.

[2] From *Energy and the Environment*, Council on Environmental Quality, 1973. These are total environmental impacts of a system associated with a 1,000-megawatt power plant with a load factor of 0.75. The waste tonnages shown for uranium are mainly produced from mining and milling of uranium ore.

[3] System controlled to minimize air and water pollution and land degradation.

[4] Light-Water-Reactors.

tantalizingly large masses in two areas of the United States.

The use of uranium as a fuel poses a different set of problems, all of which stem from the radioactivity of uranium, its so-called daughters (the sequential products of its natural distintegration), and the fission products produced in a reactor. Uranium miners face a double risk: that of accidents incident to mining any solid material, and that of breathing radon, a radioactive gas. The waste piles from the mills that process uranium ore are an environmental hazard, because they contain substantial amounts of radium, a long-lived and hazardous radioactive material that gives off radon continuously. The next three steps in what is known as the nuclear-fuel cycle pose no special environmental problems because natural uranium in a well-ventilated place is not hazardous. In the reactor of a nuclear power plant, however, the naturally fissile uranium isotope (^{235}U) is fissioned, producing much energy and a great variety of fission products, some of which are highly radioactive.

The principal problems of nuclear power are (1) how to prevent the intense and long-lived radioactivity produced in reactors from contaminating the biosphere, and (2) how to increase the efficiency of conversion of the energy in natural uranium without incurring undue social risks. In the first instance we are talking about preventing accidents that would release radioactivity from the power plants and about ways of guarding the wastes for hundreds, if not thousands, of years after they are removed from the plants. In the second case, we are talking about breeder reactors and the dangers of plutonium, which would be produced in large quantities in a breeder fueled initially with uranium and which would be recycled as new fuel for the same reactor.

Three foci of deep concern about nuclear power are: (1) the safety of the power plants; (2) the safe disposal or permanent storage of radioactive wastes; (3) the control of plutonium.

Edward Teller remarked years ago that nuclear power plants are inherently dangerous and should be placed underground. That they have not been, in the United States (there are four underground power plants in Europe), marks one of the many victories of pecuniary economics and technologic faith over prudence. The fact remains that prudent siting and contemporary protective design can make a nuclear plant compatible with the "acceptable-risk" structure of modern society. In normal operation a modern nuclear power plant emits a negligible amount of radioactivity and the chances of an accident that would breach the containment structures appear extremely remote (Nuclear Regulatory Commission, 1975).

Nor is the waste-disposal problem so intractable—if we could make up our minds what form the waste is going to be in. When fuel reprocessing was considered an integral part of the nuclear fuel cycle, high-level radioactive wastes were to be stored in liquid form at the reprocessing plant for several years and then were to be solidified and shipped to a repository for permanent storage (retrievable) or disposal (not retrievable). In this regard there were two concerns: the geological integrity of the repository, and the social integrity of the surveillance system. Because such wastes would be hazards, in terms of their most abundant radioisotopes, for upwards of a thousand years, it was deemed necessary to insure that they be kept out of the biosphere for that period of time. Certain components of these wastes, the actinides, do have discouragingly long half-lives (plutonium's is 24,300 years or thereabouts), but they are present in minor amounts, are only mildly radioactive, and the possibility appears to exist for removing them almost completely from the wastes and recycling them through the reactors for destruction by transmutation.

After much experimentation, the Atomic Energy Commission (now part of the Department of Energy) selected natural salt deposits, either in thick beds or in salt domes, as a safe storage or disposal environment for solidified high-level wastes. However, the site picked for the initial national repository, an old salt mine near Lyons, Kansas, turned out to be far from ideal, because of threats to its water-tightness from old drill holes and a nearby solution mine. A political tornado then blew the Atomic Energy Commission out of Kansas and into New Mexico where it set to work to define and test a new repository. Recent events, however, make it seem doubtful that spent fuel from nuclear power plants will be reprocessed. A different sort of repository may be needed for the spent-fuel assemblies.

The main reason for reprocessing the spent fuel was to recover "unburnt" fissile uranium and plutonium, a fissile material that is produced inside a reactor by neutron bombardment of fertile uranium. Recovery and recycling of these materials would have increased the electricity to be obtained from a given weight of natural uranium by thirty to fifty percent. As uranium reserves are being depleted, that increase in conversion efficiency could be important in extending the reserves. But the main significance of reprocessing lies in its relation to the breeder reactor, a reactor which breeds, in the form of plutonium, more fuel than it consumes in the form of uranium.

Only part of the bred plutonium will be consumed or burned before the fuel elements will need to be replaced as they become fouled with radioisotopes that inhibit the chain reaction on which the reactor depends. Consequently, reprocessing to recover plutonium, only desirable in the case of the existing light-water reactors, becomes indispensable in the case of breeder reactors.

On April 7, 1977, President Carter announced a policy position that included indefinite deferral of commercial reprocessing of spent reactor fuel and the annulment of construction plans for a demonstration breeder power plant. He made it clear that plutonium was at the heart of his decision.

What's wrong with plutonium? A great deal, according to some; not much, according to others. Besides being one of the most carcinogenic (cancer-producing) materials known, it is the essential element for producing atomic bombs. The first attribute gives it a certain scare value, although the difficulties in the way of biologically effective dispersal of plutonium dust appear formidable. It is the second characteristic that threatens to delay if not derail the nuclear-power program of the United States. Many persons feel that nuclear proliferation, the acquisition by more and more countries of the

ability to make nuclear weapons, will be accelerated if we go forward with the production and recycling of plutonium. Reprocessing technology is not secret. Neither is breeder technology. Consequently, President Carter's policy decision was an attempt at moral dissuasion, an attempt to halt development of the type of breeder that produces and requires plutonium while a search is made for a safer system. Another perceived threat with a great deal of plutonium in transit between reprocessing, fuel-fabrication, and power plants, is that a terrorist group would steal enough to make a bomb. How to make an atomic bomb no longer is a secret. Sir Brian Flowers, Chairman of the Royal Commission on Environmental Pollution, which produced a thoughtful report on nuclear power and the environment (1976), has said,

> . . . plutonium offers a unique and powerful weapon to those who are sufficiently determined to impose their will. . . . I do not believe it is a question *whether* someone will deliberately acquire it for purposes of terrorism or blackmail, but only of when and how often.

On the other side of the plutonium debate are those who see the breeder reactor creating an almost limitless supply of nuclear fuel and "a world free from energy worries" for a long time to come. Such persons will point to the fact that there has been a large quantity of plutonium in the U.S. weapons program for more than thirty years and that none has yet been diverted to malicious purpose by a nongovernment group.

The cost to the United States of delaying breeder development depends critically on how much uranium remains to be found and recovered economically as fuel for the light-water reactors, a matter of current debate and uncertainty. The largest remaining energy stock in the United States is in the form of uranium and thorium—but only if they can be used in breeders; otherwise, we shall be exhausting our nuclear fuels about the same time we run out of crude oil and natural gas, early in the coming century.

Energy Affluence and Energy Scarcity as Social Hazards

Either energy affluence or energy scarcity can be a social hazard. Energy affluence has brought great material benefits to the citizens of industrialized countries but it hasn't brought happiness in equal measure. As the ability to do things increases, the problem of determining what is worth doing grows. Because traditional religious beliefs and their attendant codes of conduct and value structures tend to be replaced by faith in material progress, what we are able to do tends to become what we want to do, and what we want to do becomes what we should do. If faith in material progress wavers, there is nothing to fall back on to guide behavior, except self-interest. Alienation and tribalism are expectable results. The United States remains the greatest high-energy country. But drug abuse, pointless violence, error-prone business, and a recrudescent belief in devils are not signs of a confident, durable society.

Humans are creatures of adversity, whose cultural ascendance has coincided with an unusual period of environmental stress in the geologic history of the world. Societies so far have shown an utter lack of ability to cope with affluence. It may be, therefore, that the vision of abundant, cheap energy and power held out by some technological optimists carries more threat to humankind than a future of energy scarcity.

The other social hazard is the severe threat to individual freedom that energy scarcity brings. David Potter (1954) argued rather persuasively that democracy is not appropriate to an economy of scarcity, because allocations of scarce resources need to be made by the few for the many. In the same year, Harrison Brown (1954: 218–219) wrote:

> It seems clear that the first major penalty man will have to pay for his rapid consumption of the earth's nonrenewable resources will be that of having to live in a world where his thoughts and actions are ever more strongly limited, where social organization has become all-pervasive, complex and inflexible, and where the state completely dominates the actions of the individual.

The most potent reason for voluntary energy conservation today is to prevent the imposition of forced conservation tomorrow. Planning should be a dirty word only when we have no voice in what is being planned.

IV. ENERGY DISTRIBUTION, CONSERVATION, AND POLITICS

Uneven Distribution and Use of Energy Resources

Energy resources are unevenly distributed throughout the world. More than half the world's arable land is within only five countries (Table 7); within these countries there is a wide range of arable land per capita, from 0.14 hectare per inhabitant in China to 3.55 hectares in Australia (based on 1970 populations). Food supply likewise is unevenly distributed geographically (Table 8); direct supply ranges from 1,750 kcal per day per person in Indonesia to 3,450 kcal in Ireland. Because there is a much larger range in the meat content of the human diet, and because it takes a lot of plant food energy to raise meat animals—the gross food and feed energy supply—what is required from the land to produce the direct food supply, ranges from about 2,270 kcal per day per person in Indonesia to almost 26,000 kcal in New Zealand. Only fifteen percent of the world's people, all of whom live in the temperate zones, enjoy a daily per capita gross food-energy supply of more than 9,600 kcal; fifty percent manage on less than 3,600.

In the distribution of beds of coal one can scarcely fail to note the general similarity to the distribution pattern of arable land. If anything, the coal measures show an even more striking preference for the temperate zones and for the northern temperate zone in particular. It is no coincidence, perhaps, that the two most powerful nations in the world produce more than forty percent of the world's coal; together they have more than three-quarters of the global reserves. Four countries have about ninety percent of all the coal, including lignite (Table 9).

Crude oil and natural gas are more widely distributed and show a different distribution than does coal. Largest known reserves (Table 10) are in the Middle East, the region that also leads in production. Although the United States was once both the major producer and the major consumer of crude oil, it now retains only the latter distinction. In fact, except for the USSR, the industrialized countries are major importers of oil, mainly from the countries that make up the Organization of Petroleum Exporting Countries. Only in the countries around the North Sea, particularly in Norway and the United Kingdom, is there, among industrialized countries, a good prospect of becoming self-sufficient in crude oil (and natural gas). Because the major consumers are distant, mostly in other continents, from the major producers of crude oil, there is a great deal of oil transported by tankers across the oceans (Figure 4), mainly from the Middle East to Western Europe and Japan, from Africa to Europe and North America, and from Venezuela to North America. Because of the difficulty and expense of transporting natural gas in tankers, it is only recently that the intercontinental movement of this fuel has shown signs of accelerating rapidly.

The world's largest potential reserves of oil shale appear to be in the United States; commercial production has occurred mainly in Scotland, the USSR, and China. The major actual and potential reserves of tar-sand oil appear to be in Canada, although Colombia and Siberia may contain tar sands of equal or greater potential.

Much less is known about uranium reserves than about hydrocarbon reserves. Once again, however, reserves appear to be concentrated in a few countries, principally the U.S., Canada, South Africa, the USSR,

TABLE 7. ARABLE LAND, MAIN COUNTRIES, 1970

Nation	% of World Total	Ha/Person
USSR	16.1	0.94
USA	12.3	0.85
India	11.1	0.30
China	7.7	0.14
Australia	3.1	3.55
Canada	3.0	2.04
Brazil	2.1	0.32
	55.4	

Source: *Production Yearbook 1970*, Vol. 24, United Nations Food and Agriculture Organization (Rome: 1971).

TABLE 8. DAILY PER CAPITA FOOD SUPPLY IN KCAL FOR SELECTED COUNTRIES, 1970

Nation	Net supply	Gross supply
New Zealand	3,320	25,900
USA	3,290	16,200
Ireland	3,450	15,700
United Kingdom	3,180	14,200
Israel	2,930	10,400
Sweden	2,750	9,300
USSR	3,180	9,000
Italy	2,950	7,900
Brazil	2,540	7,000
Mexico	2,620	5,700
Portugal	2,730	5,000
Japan	2,450	4,200
China	2,050	3,300
India	1,940	2,500
Indonesia	1,750	2,270

Source: Data on net supply from *Production Yearbook 1970*, United Nations Food and Agriculture Organization (Rome: 1971)

France, and Australia. This distribution may be more historic and economic than geologic, however, for those are countries that have had the desire and the capital to mount intensive exploration programs for uranium, either because of its military importance or because of the need to replace fossil fuels for power generation, or both.

Another energy resource whose present exploitation is largely based on economic history rather than on distribution of the basic potential is hydroelectricity. Latin America and Africa together have almost half the world's potential, but generate only about two percent of the world's hydropower. Western Europe and North America, with only seventeen percent of the potential, produce about half the hydropower. Countries that derive more than seventy percent of their electricity from the energy of falling water include Canada, the USSR, Norway, Sweden, Brazil, Switzerland, and New Zealand. More than sixty percent of all electricity is generated in two small areas of the world, North America and Western Europe. Electrification clearly is a result of affluence, rather than a cause of it.

With existing technology, geothermal power appears limited to certain areas of geologically recent volcanism where heat may be trapped in water or steam near the earth's surface. Even if dry hot rocks can be exploited economically, the greatest potential will still lie in such areas. In the Americas, that means the cordilleran regions. There is a possibility that the hot water and the natural gas dissolved in it that are found in certain "geopressured" sedimentary basins, such as that under the Gulf Coastal Plain in Texas and Louisiana, can be exploited for both geothermal and fossil-fuel energy.

One of the great attractions of solar energy is its very wide geographic distribution. Any country could make some use of it, and many countries that are poor in other energy resources are rich in sunlight. Unlike the case of nuclear power, including fusion power, a country need not be already rich to be able to afford to make substantial use of solar energy. On the other hand it would help to be rich, especially if one wishes to make full use of solar electricity generating systems. A country such as Saudi Arabia may be in an almost ideal geographic and economic situation about the year 2000 when it will need to start moving from oil and gas to solar energy as the basis of its strength.

TABLE 9. WORLD COAL RESERVES, MAJOR COUNTRIES, 1966

Nation	% of World Total
USSR	56.4
USA	19.5
Asia (mainly China)	8.9
Canada	7.9

Source: Paul Averitt, *Coal Resources of the United States, January 1, 1967*, from Cook, 1967. Reprinted by permission of W. H. Freeman and Company.

TABLE 10. RESERVES AND DAILY PRODUCTION OF CRUDE OIL AND NATURAL GAS, MAJOR COUNTRIES

Nation	Crude Oil			Natural Gas		
	Reserves+ (10^9 bbls)	Percentage of World Reserves	Production× (10^3 bbls)	Reserves+ 10^9 cu ft	Percentage of World Reserves	Production× 10^6 cu ft
Saudi Arabia[OX]	113,150	18.9	9,352	65,500	2.8	335
USSR	78,100	13.0	10,809	918,000	39.4	33,154
Kuwait[OX]	70,550	11.8	1,678	34,200	1.5	554
Iran	63,000	10.5	5,604	330,000	14.3	4,713
Iraq[OX]	34,000	5.8	2,165	27,000	1.2	382
USA	31,300	5.2	7,966	220,000	9.6	54,924
Abu Dhabi[OX]	29,000	4.8	1,679	20,000	0.9	398
Libya[OX]	25,500	4.3	2,073	25,800	1.1	1,345
China	20,000	3.3	1,750	25,000	1.1	4,711
Nigeria[O]	19,500	3.3	2,204	44,000	1.8	1,987
United Kingdom	16,800	2.8	713	30,000	1.3	4,707
Venezuela[O]	15,270	2.6	2,266	40,700	1.8	1,090
Indonesia[O]	10,500	1.8	1,694	24,000	1.0	912
Mexico	7,000	1.2	967	12,000	0.5	2,045
Algeria[O]	6,800	1.1	1,036	125,800	5.5	697
Canada	6,200	1.0	1,390	56,000	2.4	6,224
Norway	5,660	0.9	264	18,500	0.8	—
Netherlands*	91	—	30	61,900	2.7	10,462

+ As of January 1, 1977. Estimated from *Oil and Gas Journal*, Dec. 27, 1976, p. 104–105.
× This is the daily average for the first six months of 1977, calculated from figures given in *Oil and Gas Journal*, Aug. 29, 1977, p. 86
O = Member of OPEC (Organization of Petroleum Exporting Countries).
X = Member of OAPEC (Organization of Arab Petroleum Exporting Countries).
* Included because of its large gas reserves and production.
Note: Reserves and production of Neutral Zone have been allocated in this table equally to Saudi Arabia and Kuwait.

Map on page 16 has been removed by ERIC due to copyright law.

Figure 4. International oil flows, 1976. Units are thousands of barrels per day. Reproduced from *International Petroleum Encyclopedia 1977* by permission of The Petroleum Publishing Company, Tulsa, OK.

Not One World, But Four

There are now at least four "worlds" into which the nations of the earth may be divided on the basis of access to and management of energy resources (Cook, 1976:257):

1. *The high-energy world of the market economies,* most of which are now, for the first time in their history of industrialization, short of energy and dependent on continued imports of petroleum, whose production and distribution they no longer control, in order to maintain their economic and social systems. They have rates of energy consumption above 50,000 kcal per person per day (Table 11) and moderately low rates of population growth (about one percent per year).

2. *The world of the planned or socialist economies,* in various stages of industrialization. The two principal nations, the Soviet Union and China, are self-sufficient in energy and are able to export some oil and natural gas, which enables them to buy technology and certain strategic materials from the market-economy countries and to strengthen their political bonds with their energy-deficient satellites. These nations show a wide range of energy consumption rates, from China's 11,000 kcal per person per day to the Soviet Union's 90,000. They have an average rate of population growth similar to that of the first world.

3. *The world of OPEC,* composed of countries that export substantial amounts of petroleum and that have seventy percent of the world's reserves. Their level of industrialization is low, except in the fields of petroleum exploitation and petrochemical manufacturing (including fertilizers). Mexico has become a member of this world, although not yet a member of OPEC. Calculated energy consumption rates show the greatest range of the four worlds, but that is because of the large amounts of energy used in the petroleum industry in some countries with small populations, such as Kuwait and Bahrein. Rates of population growth are high, averaging about three percent per year; exceptionally high rates characterize the Arab countries (Kuwait's was estimated at 6.1 percent in 1976).

4. *All other countries.* Daily per capita energy consumption rates for most of these countries are below 25,000 kcal and for many are less than 5,000 kcal (food, wood, and waste fuels not included). Steep rises in world prices for food and energy have exacerbated the struggle for economic advancement in many of these countries. Some have export resources, such as copper, bauxite, coffee, bananas, or sugar, but earnings from these tend to be unmanageably cyclic. Rates of population growth average about three percent per year.

Daily energy consumption throughout the world ranges from more than 200,000 kcal per person in North America down to less than 4,000 in India, Pakistan, and Indonesia. If food and vegetable fuels were included, the upper figures wouldn't be changed much, but the lower ones would be tripled, to 10,000 or more kcal. Even so, the range is great, some twenty to twenty-five times.

The major uses of nonfood energy are for comfort heating and cooling (including cooking and water heating), and for mechanical work. In a low-energy society, the use of energy in industry and transport is minor; in a high-energy society, these uses are major components of the energy-flow system. In the United States, fifty percent of the crude-oil consumption is represented by motor fuel; in Europe, only seventeen percent, and in the rest of the world, less than five percent. Grain fed to animals follows a similar distribution pattern.

TABLE 11. PER CAPITA DAILY ENERGY CONSUMPTION IN SELECTED COUNTRIES, 1974

USA	216,500 kcal	New Zealand	64,916 kcal
Kuwait	186,850	Italy	60,769
Canada	185,000	Israel	54,926
Bahrein	139,143	South Africa	51,910
E. Germany	130,925	Spain	38,885
Czechoslovakia	128,663	*World average*	*38,810*
Belgium	126,458	Greece	38,603
Developed countries average	*119,672*	Argentina	35,078
		Mexico	23,919
		Iran	23,901
Netherlands	116,694	Portugal	19,339
Australia	113,037	Saudi Arabia	18,397
Sweden	109,399	Brazil	12,290
W. Germany	107,402	Peru	12,252
United Kingdom	102,991	China	12,252
		Undeveloped countries average	*7,427*
USSR	98,995		
Denmark	96,394	Egypt	6,069
Norway	92,831	India	3,789
Poland	88,345	Pakistan	3,619
France	81,842	Indonesia	2,978
Switzerland	68,158	Nepal	226
Japan	72,361		

Note: Fossil, nuclear, geothermal, and hydroelectric energy only; food and feed, fuel wood, fuel from animal and vegetable wastes are not included.

Source: *World Energy Supplies, 1950–1974,* United Nations (1976).

Twenty percent of the world's people consume seventy-two percent of the world's inanimate energy supply; fifty percent consume only eight percent. Although in nonindustrial countries energy supplies may be used inefficiently (fuel in some primitive devices probably is burned with as little as five percent of its latent energy converted into cooked food and hot water), the potential for saving or conserving large amounts is in the high-energy societies. It is a paradoxical truth that one who wastes a lot has a great potential for conservation.

The American Energy Economy

The flow of energy (except biomass) through the U.S. economy (Figure 5) illustrates the almost total dependence of the nation on fossil fuel as well as the degree to which the system depends on energy imports. Although but twenty percent of the total energy consumption in 1975 was from imported resources, most of those imports were destined for the transport sector of the economy. Of the petroleum consumed that year 43.5 percent was imported.

More than fifty percent of the petroleum consumed was used as motor fuel. It is therefore the transport system that is most vulnerable to interdiction of foreign supplies, and that will be most affected by an increasing scarcity of petroleum.

Energy used in the United States, classified by end uses, is shown in Table 12. The largest use of energy is for space heating and cooling; if one includes refrigeration and freezing, this category accounts for more

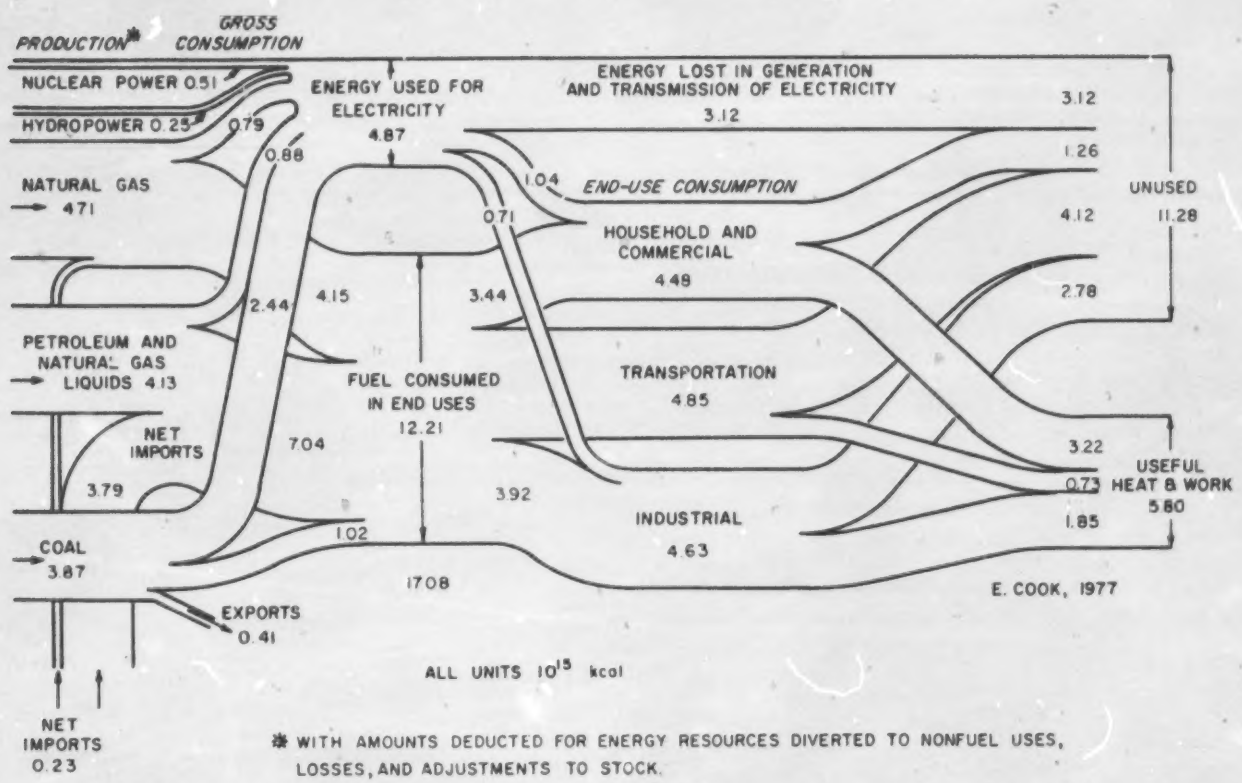

Figure 5. Flow of energy through the U.S. economy, 1976. Based on statistics in U.S. Bureau of Mines press release dated March 14, 1977.

than a quarter of all energy used. Another twenty percent is used in highway vehicles; it is a mark of economic development that the transport of people takes more energy than the transport of all freight, including the oil and gas that move through pipelines. A large amount of energy, about fifteen percent, is required by the extractive industries, those that mine ores and smelt them, that pump oil and refine it, that quarry clay, sand, and limestone to make bricks, glass, and cement.

Transport of freight uses about ten percent of the nation's energy supply. These four uses (space conditioning, people transport, extractive industry, and freight haulage) account for seventy percent of all energy consumed. Most of the remainder is used in manufacturing and construction.

Conserving Energy

Conserving energy has trenchant significance for those countries, such as the United States, whose economy and life-style are dependent on wasting energy assets, the fossil fuels. But the United States remains exceptionally favored in that it still has very large reserves of such assets in the form of coal and still larger potential reserves of uranium and thorium if it is decided to deploy breeder reactors. There are many other countries which do not have such options and where conservation is a question of stretching the available nonrenewable energy as far as practicable, in part because of its present cost, but mainly because of the anticipated costs of running out (domestic supply) or interdiction (foreign supply).

In the physical sense, energy will be conserved, willy-nilly. We can't destroy it. But we can and do destroy its utility or availability, and what we mean by conservation is to get the most we can out of a drop of oil or a lump of coal before the latent energy in it has been turned into heat at ambient or environmental temperatures and has thereby become useless, perhaps even harmful to us.

There are three important elements in conservation: technical efficiency, social utility, and pecuniary costs. It is relatively easy to implement conservation if technical efficiency can be improved with no decrease in social benefits and no increase in pecuniary costs. Even then, if the economic payoff is to be delayed and there is an added initial expense as in home insulation or energy-efficient air conditioners, effective conservation may require tax incentives and government regulations for its effective implementation. Most energy conservation entails some costs that cannot be recouped; they may be in social utility or convenience, as when the speed or mileage of an automobile is restricted or a house thermostat is set lower or higher than desired; or they may be in additional dollars expended, as when a high-cost fuel is substituted in an industrial process in order to conserve natural gas for residential use.

Technical efficiency analysis or energy accounting can

TABLE 12. DISTRIBUTION OF TOTAL U.S. ENERGY CONSUMPTION BY END USES

Approximate distribution of energy used in U.S. transportation (1975)

Type of transport	*Energy**	*Percent of Subtotal*	*Percent of Total*
Automobiles	2.26	49	13.8
Trucks	0.90	19	5.5
Pipelines	0.40	8.5	2.4
Aircraft, civilian	0.36	8	2.2
Military	0.35	7.5	2.1
Waterways	0.18	4	1.1
Railroads	0.14	3	0.9
Buses	0.03	1	0.2
Motorcycles	0.01	0	0.1
	4.63	100	28.3

Source: Mutch (1973), p. 15, adjusted to 1975 total as given by U.S. Bureau of Mines.

Approximate distribution of energy used in U.S. industry (1975)

Type of industry	*Energy*	*Percent of Subtotal*	*Percent of Total*
Primary metal industries	1.25	21	7.6
Chemicals and allied products	1.24	21	7.6
Petroleum refining and related industries	0.62	10	3.8
Food and kindred products	0.32	5	2.0
Paper and allied products	0.30	5	1.8
Stone, glass, clay, concrete	0.29	5	1.8
Mineral and other manufacturing industries	1.94	33	11.9
	5.96	100	36.5

Source: U.S. Bureau of Mines (1971), p. 26, adjusted to 1975 total as derived from U.S. Bureau of Mines data.

Approximate distribution of energy used in U.S. homes and commerce (1975)

End use	*Energy*	*Percent of Subtotal*	*Percent of Total*
Space heating	3.16	55	19.4
Water heating	0.69	12	4.2
Air conditioning	0.55	9.5	3.4
Refrigeration and freezing	0.49	8.5	3.0
Lighting	0.29	5	1.8
Cooking	0.23	4	1.4
Electric motors (other than for air-conditioning and refrigeration)	0.17	3	1.0
Television and clothes drying	0.17	3	1.0
	5.75	100	35.2

Source: Stanford Research Institute (1972), pp. 36, 67, adjusted to 1975 total as derived from U.S. Bureau of Mines data.

* All units are 10^{15} kcal.

suggest where savings can be made. Economic analysis is then needed to determine both the money costs of alternatives and their impacts on employment and income. Finally, social analysis is required to determine the most effective way of achieving acceptance of a more efficient alternative.

Where Energy Could Be Conserved in the United States

The energy-system efficiency of the American automobile is about five percent (Figure 6). This comes about partly because of the inherent inefficiency of any combustion engine (those in automobiles run at about thirty percent thermal efficiency) and partly because the desire for comfort and convenience has added a great deal to the energy losses in other parts of the machine. The major inefficiency in the American automobile, however, does not appear in the diagram. The American car is much heavier than it needs to be for transport alone. In recent years the average American car has weighed twice as much as the average of cars used in the rest of the world. Because the fuel consumption of cars, on the average, is proportional to their weights (the fuel economy of an individual car, however, varies greatly with the speed at which it is driven), the energy used to

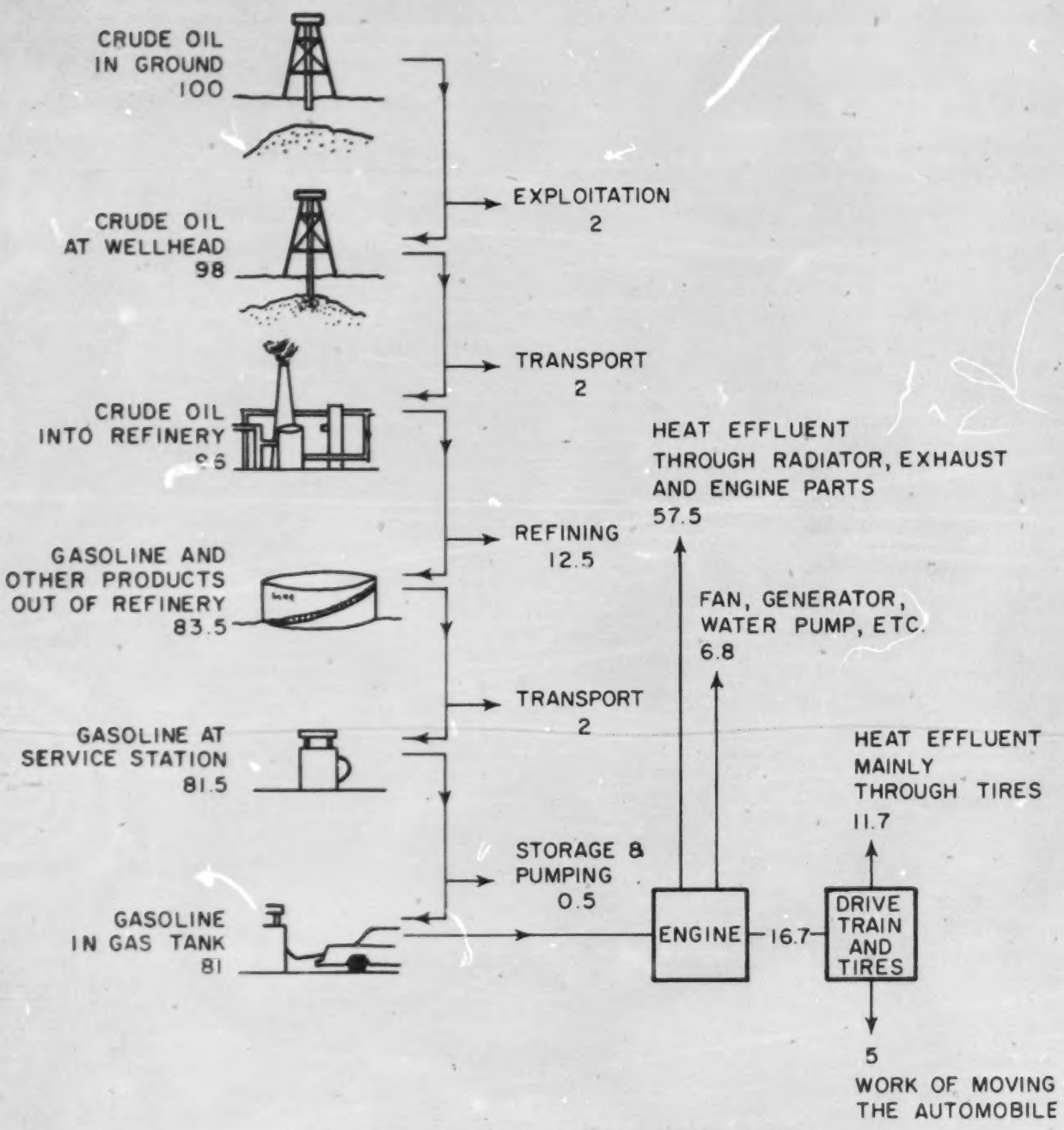

Figure 6. Energy-system efficiency of the American automobile.

propel cars in the U.S. has been at least twice that needed to get the job done, and more when one considers the energy costs of power steering, air conditioning, automatic transmission, and other conveniences. If at the time of the Arab oil embargo in 1973–1974. American cars had been the same weight as other cars in the world and had they been driven at fifty-five mph or less, the embargo would have had no effect on the U.S. economy, for we would not have been importing oil.

Raising the price of gasoline has been proposed by many, including President Carter, as a means of lessening consumption. Eric Hirst, who has devoted much time to studies of the use of energy in transportation, concludes (1976b:15) that behavioral changes such as greater use of mass transit, carpooling, and driving at speeds of fifty-five mph or less are "surprisingly insensitive to purely economic forces unless they are so strong as to be politically unfeasible." This conclusion is supported by Mexico's experience, where a tripling of the price of gasoline over a five-year period only slightly

slowed the rate of increase in consumption. Hirst believes that significant passenger transport energy savings can be achieved only by improving new car fuel economy. Our cities and our life-styles are structured for the use of the automobile; consequently, it will not be abandoned, it will be altered. It will be made lighter; it will have fewer energy-consuming conveniences and accessories it must ultimately use fuel that does not come from crude oil; and it may even have its internal-combustion engine replaced by batteries. But the automobile will persist, for it is easier to change than are people. Ross and Williams (1977) calculate that the fuel economy of the American automobile could be improved by 150 percent, more than halving the gasoline demand, and that more modest savings in other transport modes could reduce total energy consumption in transportation, which was 4.63 quadrillion (10^{15}) kcal in 1975, to 2.34 quadrillion. The energy in all petroleum imported in 1975 was 3.21 quadrillion kcal.

Only recently has energy efficiency become a factor in the design and construction of American homes and offices. The cheapness of energy for heating and cooling made it uneconomic to pay much attention to insulation, to window sizes and types, and to the system efficiencies of the heating and cooling systems to be installed. Ross and Williams (1977:50) believe that potential energy savings of 2.92 quadrillion kcal could be made in the residential and commercial sectors, or more than half the amount used in 1975, when allowance is made for the fuel used to generate electricity. These savings could be accomplished by replacing electric heating with heat pumps, by increasing the efficiency of air conditioning and refrigeration, by reducing water heating requirements and heat losses caused by inadequate insulation and poor window design, by introducing total-energy systems to provide heating, cooling, and electricity from the same source, and by using microwave ovens for much of the cooking. District-heating systems (Karkheck, Powell, and Beardsworth, 1977) could also effect significant reductions in fossil-fuel consumption; these are systems designed to heat all buildings within an area from a central source, by steam or hot water.

Improvements in energy use have been made faster in industry under the stimulus of higher energy costs than they have in the other economic sectors. Blast furnaces, glass furnaces, cement kilns, and oil refineries have used cheap fuel inefficiently, but these devices are being improved to waste less heat and to recover and recycle usable heat that previously was being lost. There is still much room for improvement, especially through better management practices.

A fact of great significance is that the efficiency of energy use in the United States has been rising for more than a century (Figure 7) and that in general it was nearing a plateau when the energy "crisis" was perceived. Future improvements, therefore, must come largely from better operation and management of existing systems (conserving behavior) rather than from technological breakthroughs that will allow incremental jumps in efficiency. Here it must be pointed out that conservation is not synonymous with increased efficiency of use. A less efficient system, say one based on solar energy or nuclear power, when substituted for a more efficient system based on natural gas, will conserve the gas although it may "waste" energy.

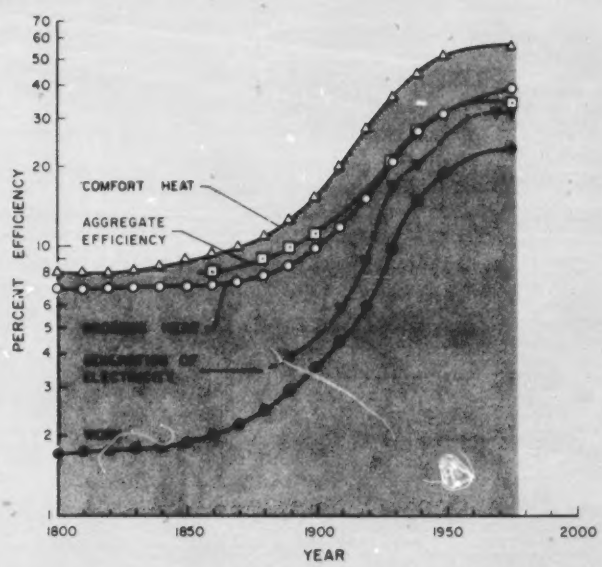

Figure 7. Efficiencies of energy use in the United States, 1800-1972.

It appears possible to cut U.S. energy consumption in half without seriously affecting life-styles or the production of goods and services. Hannon (1977) has shown how a society determined to save energy could increase economic stability, employment, and social equity. Other authors (Schipper, 1976; Widmer and Gyftopoulos, 1977) support this view, arguing that strict energy conservation will not only increase, rather than decrease, employment but should also have substantial environmental benefits. Some sceptics, however, noting the general accordance throughout the world of high energy consumption with high per capita income and national prosperity fear that a decrease in energy consumption will bring added unemployment and a lowered standard of living.

The Politics of Energy

The politics of energy derive from (a) an uneven distribution of the primary resources and of the demand for them, (b) the desire of groups or nations to capitalize these resources for their own ends, and (c) the desire to avoid or minimize the adverse environmental impacts of energy exploitation.

Western Europe and North America fueled their early industrialization on indigenous water power, fuel wood, and coal. When Western Europe's industrial growth outreached its coal resources, its new base became imported petroleum. North America had lots of oil; its transition from coal was easy, but in recent years, as domestic production has declined, the U.S. also has come to rely more and more on imported oil. Japan had only a little coal and oil; it first tried conquest to obtain

coal in Manchuria and oil in Southeast Asia, but then came to rely on purchased imported oil.

As long as foreign oil resources and the means of exploiting them were firmly in the hands of the major international oil companies, owned and operated mainly by citizens of North America and Western Europe, increasing reliance on imported oil did not seem a serious threat to the economy or security of the consuming countries. Through the oil companies, their home countries (United States, United Kingdom, Netherlands, France) were assured not only of the energy they needed for economic growth and military strength but also of large repatriated profits from overseas operations. But control of international oil flows by the distributors and consumers of oil no longer exists. These flows (see Figure 4) are now controlled largely by the producing countries through the Organization of Petroleum Exporting Countries (OPEC).

The change came about through competition. First, some American companies of the second rank, unhappy with the rising costs and dimming prospects of finding oil in the United States, decided to go to the foreign producing countries and compete with the majors for exploration concessions and production contracts. Second, the Soviet Union started selling and bartering Soviet oil below the price maintained by the international companies. Third, an aggressive Italian government corporation named Ente Nazionali Idrocarburi entered the competition for exploration concessions, offering the producing countries not only larger shares of the petroleum to be discovered, but, more importantly, "participation" in the actual ownership and management of the extraction, refining, and distribution system. These three elements produced a decade or more of the cheapest energy the world has ever seen, and probably will ever see, and set the stage for the emergence of OPEC as a powerful cartel. By 1975 OPEC had imposed artificial prices on the consuming nations that were four times the 1970 levels and individual members were expelling the foreign companies or dictating the terms under which they might be able to continue to participate in the refining and distribution of OPEC oil.

Late in 1973 the Arab members of OPEC attempted to stop the flow of Arab oil to the United States and the Netherlands and limit its flow to Western Europe and Japan in order to bring pressure on the governments of the consumer countries to lessen or renounce economic and political support of Israel. The ostensible objective was not achieved, but clearly because the Arabs relented, not because of resistance by the consumer countries. The Dutch were stubborn, the Americans hortatory, the Japanese and French propitiatory. The power of oil as an international political weapon was demonstrated, and those who can wield the club clearly identified, which was the probable purpose of the exercise. That power will likely remain where it is through the climax of the petroleum age, because (1) it is extremely unlikely that reserves of the magnitude of those in the Middle East will be found anywhere else; (2) neither the Soviets nor the Americans will allow the "other side" to take physical possession of the Middle East reserves; (3) there is formidable military power growing in that region which, if it is not destroyed in inter-Moslem strife, should serve to keep any "protection" proffered at bay.

The eventual fate of Israel is a matter of concern and conjecture, ineluctably entangled in the politics of oil. The profligacy of Americans, the principal supporters of Israel, in wasting oil and thus becoming more dependent on supplies from the Arabs, the principal enemies of Israel, appears to be bringing closer the time when the United States might judge that it could no longer risk coming to the aid of Israel.

This brief discussion may serve to illustrate how closely the politics of energy are tied to the technology of energy. If the major industrial countries were not so addicted to the abundant use of petroleum products, especially motor fuel, they needn't be so sensitive to political pressure from the supplier countries. France, which imports more than eighty percent of its energy, decided a few years ago to develop nuclear power as fast as practicable in order to improve its economic security and its position in international energy politics. In the United States, either substantial improvements in the efficiency of use of motor fuel and fuel oil or significant substitution of coal as a base for fluid fuels would allow a more independent international posture.

For many years, the United States was accused of practicing "oil diplomacy," of trying by shrewd means and crude to make the world safe and profitable for the big oil companies, who were widely regarded as agents of American economic imperialism. Now, the United States, having long abandoned any economic or political cooperation between its government and its oil companies, having in fact created a state of continuous warfare between them, is faced with the club of oil wielded by others, and can only hope that it will be wielded with prudence.

Within the United States, the distribution of primary energy resources likewise is part of the frame for political action. A contiguous group of five states—Texas, Louisiana, Oklahoma, New Mexico, and Kansas—produces more than ninety percent of the nation's natural gas and almost seventy-five percent of domestic crude oil. In those states the political stance in regard to such matters as federal price control of gas and oil differs from the political stance on the same subject in major consuming states, which produce little or no fossil energy. There is little sympathy for citizens of states that try to block offshore drilling for oil while continuing to consume large quantities of oil and gas whose prices are kept artificially low by the political power of the consumers. Consumer states are illustrated by New York, New Jersey, and the New England states, which import more energy than all the countries of South America and Africa use, while producing virtually none. Most of their imported energy is in the form of natural gas and petroleum. In such states the political stance is that oil and gas prices should be kept as low as possible, and rationalization of this position, in terms of "windfall" or "obscene" profits of the big oil companies and "hidden" reserves of the Texas gas producers, is common. People believe what they want to believe, and it often accords remarkably well with their perceived self-interest,

whether they live in New England or Texas. More importantly, the major gas and oil producing states have ten senators in the U.S. Congress; the others have ninety.

In addition to regional self-interest, the politics of conservation play a role in domestic energy arguments. The politics of conservation are fashioned from two concerns: (1) that there be equity in the distribution of the material benefits and the social costs of resource exploitation, and (2) that there be something useful and enjoyable left for future generations. Thus conservation covers both the exploitation of resources and the management of the environment, and it has clear and unavoidable links to the politics of enterprise, that is to political expression and action derived from concepts of how scarce resources should be managed. In U.S. energy politics, there is a fitful alliance among (a) consumers concerned about rising energy prices; (b) conservationists concerned about air and water pollution, the scars of strip-mining, and other environmental costs of energy use; (c) those who want to minimize the adverse economic and social impacts of the depletion of domestic supplies of nonrenewable energy resources, while searching for adequate substitute energy systems; (d) those who believe it necessary to limit economic and population growth and who see control of energy as the key to such limitation; and (e) those who believe that resources as vital to society as those of energy should not be managed by private industry.

These concerns and positions are far from frivolous, but their objective consideration often seems impeded by the desire for a quick political fix and the attendant search for scapegoats. For all these groups the oil and gas industry presents targets of convenience. Although the industry no longer appears to have much political power except in those states where it is a major element in the economy, it is the expressed view of many politicians and journalist-commentators that it still does have great and malign power; they point to its interests in oil shale, coal, uranium, and even in geothermal and solar energy, to make the industry appear to be a growing energy octopus which threatens to produce monopoly pricing in all energy, an inequitable distribution of the benefits of energy, and a lessening of the national purpose in conservation and environmental quality.

The contemporary drive in the U.S. Congress to enact "horizontal divestiture" is a cogent illustration of the desire for a political fix that will ameliorate a problem of scarcity, the threat of inequity that looms whenever a relatively small group gets management control of a vital resource. Horizontal divestiture would prevent a company with its major interest in oil and gas production, processing, and distribution from acquiring interests in any other form of energy production; those oil companies which now have such interests would be forced to divest them, to sell them to someone not in the oil business. An oil company could not produce coal as Exxon now does, or uranium as Conoco does, or get into geothermal energy as Shell has. The implication is that the antitrust laws cannot be expected to work sufficiently well in the face of the great political power of the energy companies, and that competition among energy companies is too weak to protect the public interest.

There is here a very real political dilemma for a country founded on free enterprise and nurtured on its mythology. On the one hand, it can be argued that energy is to a modern nation as salt was to an ancient one, and that energy, like salt in the ancient world, should be a government monopoly. But that goes against the free enterprise grain and therefore compromises are sought; federal price controls are imposed on natural gas and crude oil (but not on coal or uranium); breakup of the major oil and gas companies is attempted. On the other side, it can be argued that the antitrust statutes do work, that there is competition among energy companies (a gas station on each of the four corners of many of our major street intersections is striking visual evidence of competition), and that forced divestiture is against the national interest because the capital and expert personnel of the large companies can be very effective, not only in squeezing more oil and gas out of American reservoirs but in implementing large alternative energy systems more speedily than could many small companies, and more efficiently than could government.

A point that should be made is that horizontal divestiture would condemn the U.S. oil and gas industry to a death by attrition, as the domestic supplies of oil and gas are depleted to exhaustion. The foreign future of the major companies cannot excite any bright young person considering entering the industry. The major companies will continue essentially as contractors for the producing countries, at the discretion of the producing countries. They will also remain as refiners and distributors only until forced out of these activities either by the producing or consuming countries. If restricted in the United States to producing oil and gas, both of which probably will be well along toward exhaustion in only twenty more years, the present flow of capital out of the industry will become a flood because investments in oil and gas operations are becoming less profitable than investments in alternative enterprises.

In the United States, much of the public views the major oil companies as acting contrary to the public and national interest. This has never been the case in Great Britain in regard to British Petroleum, seen as a national asset and used as an agent of national policy. Of course, the fact that the British government owns a major share (but does not vote its stock) in the company may make a difference in its public image. British Petroleum recently has made a substantial investment in coal reserves in Australia. It could not buy a coal mine at home, because coal in Britain is a nationalized industry.

Nuclear politics deserves separate mention, because here government is not a fair maiden in a gilded cage of corporate corruption, but a hardened partner in a feared military-industrial establishment that, for its own venal ends, wishes to impose on present and future generations monstrous risks of cancer, deformity, and holocaust. Rational voices seeking clarification of issues, ways of estimating unprecedented risks, and a basis for prudent exploration of technologic alternatives, tend to be drowned by emotional cries for banning nuclear facilities entirely or for construction and operating standards

so stringent as to be almost prohibitive. In 1977 Louisiana passed a law that prohibits disposal or storage of radioactive waste in any salt dome in the state; other states have indicated that they want no part of a radioactive-waste repository, although they appear to be willing to accept the electricity that produces the waste.

The present tragedy of energy politics is that the sound and fury of debate over "windfall profits," "hidden reserves," "price conspiracies," oil spill "disasters," "monopolistic practices," and environmental "rape," trumpeted by politicians and magnified by the media lead to patchwork solutions intended to relieve political pressures. Such pressures are in part created by the people who have the "solution" already in draft, and obscure not only the facts but definition of the central problem, which is how to achieve a sustainable energy equilibrium without drastic revision of our society. This is a grave and complex problem, one that will require good will from people of differing persuasions, cooperation from people of differing interests, and agreement on the basic facts. None of these is visible today. It is ironic indeed that the Shah of Iran and the Petroleum Minister of Saudi Arabia have been preaching to deaf American ears that petroleum is an ephemeral resource, that it should not be wasted, and that adequate replacement for it must be sought assiduously for the welfare of humanity.

V. SOURCES OF STATISTICAL INFORMATION

The student of energy will find that some quantitative information is readily available; for example, statistics on the production of food, the fossil fuels, and electricity. Some is available but requires an understanding of the basis for calculating the numbers; for example, reserve and "resource" estimates for the fossil and nuclear fuels. Some is hard to find and may call for checking with other sources as well as a judgment as to its applicability in the context desired; for example, the technical efficiency of energy-conversion devices and systems. Finally, some information simply is unavailable except as informed guesses; for example, quantities of wood and waste materials used as fuel, and the efficiencies of use of such fuels. The increased interest in energy over the last few years has stimulated efforts to fill information gaps, but the quantifying task of the geographers of energy, commonly interested in total systems more than in specific elements of those systems, remains difficult. This section is intended to lead the neophyte in energy to basic data sources. It is far from inclusive. Some of the sources listed below go beyond energy resources and systems; in those instances, only the included energy information is indicated. *Energy Information Abstracts*, published bimonthly by Environment Information Center, Inc., 292 Madison Avenue, New York, NY 10017, is a comprehensive guide to books, periodicals, and other documents relating to energy. A useful bibliography, although somewhat out of date, is U.S. Geological Survey Circular 641 (1970), titled *Selected Sources of Information on United States and World Energy Resources: An Annotated Bibliography*. A comprehensive guide to the statistical publications of the U.S. Government is the *American Statistics Index*, published annually by Congressional Information Service, 7101 Wisconsin Ave., N.W., Washington, D.C. 20014. The *Monthly Energy Review*, published for the Federal Energy Administration* by the National Technical Information Service (NTIS), contains data and text on energy fuels, electricity production, and oil and gas exploration activity. A formidable guide to *Energy Information in the Federal Government* was published by NTIS in 1976; it identified 261 energy-related programs of forty-four federal agencies or bureaus, and has more than a thousand pages; annual updates are planned.

Agricultural Statistics (annual), U.S. Department of Agriculture, Washington, D.C. (Government Printing Office).

Production and prices of U.S. cash crops, livestock, meat, and dairy products. Feed disappearance data. Imports and exports. Farm resources and economics. Food consumption.

FAO Production Yearbook (annual), United Nations Food and Agriculture Organization, Rome.

Grain and meat production by country. Fertilizer and pesticide production and use. Livestock and farm machinery census. Prices of agricultural commodities and wages.

UN Statistical Yearbook (annual), United Nations, New York.

World population and indexes of domestic production by countries. Agricultural production and food consumption. World production of primary commodities, manufactured goods and energy. Production statistics on selected crops, forestry, fishing, industries, mining, and manufacturing by country. Also tables on finance, housing, health, education, and other cultural parameters.

US Food Consumption-Sources of Data and Trends, 1909–1963 (irregular supplements), Statistical Bulletin 364, U.S. Department of Agriculture, Washington, D.C. (Government Printing Office).

Annual per capita consumption of all foods for U.S. civilian population and the nutritive values of this food.

* On October 1, 1977, the Federal Energy Administration was absorbed into the new Department of Energy, as was the Energy Research and Development Administration.

Annual supply and utilization tables for individual foods. The same tables for 1960–1966 are in *Food Consumption, Prices, Expenditures,* Agricultural Economic Report No. 138. Years 1966–1973 are in *Supplement to Agr. Econ. Report No. 138.* A still later supplement includes 1975.

National and State Livestock-Feed Relationships (irregular series; latest is Economic Research Service Statistical Bulletin 530, Supplement 1975), U.S. Department of Agriculture, Washington, D.C. (Government Printing Office).

Consumption of all feeds, hay, and pasturage by types of livestock given both in actual tons and in equivalent feed units. National and state indexes relating livestock numbers and production to feed consumption by kinds of livestock and their corresponding products.

Composition of Foods. Agriculture Handbook No. 8, Agricultural Research Service, U.S. Department of Agriculture, Washington, D.C. (Government Printing Office).

Energy, protein, fat, carbohydrate, mineral, and vitamin content of nearly 2,500 food items. Energy values in this reference represent the energy available to the human body after deductions from the gross energy content (heat of combustion) for losses in digestion and metabolism. Although the figures obtained are not the same as figures calculated for some of the same food items for other animals, there is a convenient unit of conversion called the corn-equivalent feed unit (CFU), used to compare different feeds for different animals, that allows energy-flow calculations of the type illustrated by Figure 2 in this paper, enabling one to compare feed-energy input with food-energy output in livestock culture. The corn-equivalent feed unit, for such a purpose, may be taken as 1,600 kcal.

World Energy Supplies (annual), Department of Economic and Social Affairs, Statistical Papers Series J, United Nations, New York.

Production, trade, and consumption of fossil fuels, petroleum products, and electricity by country, region, and world. Installed electrical generating capacity and utilization. Production of uranium.

Historical Fuels and Energy Consumption Data, 1960–1972, U.S. by States and Census Districts. U.S. Bureau of Mines Information Circulars 8704, 8705 (1976). Washington, D.C. (Government Printing Office). Annual supplements (1974 data published in Information Circular 8739, in 1977).

The first circular includes areas east of the Mississippi, the second, areas west of the Mississippi. Reserves, production, consumption of oil, gas, coal, uranium by state. Energy consumption by economic sector for coal, oil, gas, hydroelectricity, and nuclear power. Useful for correlations of population density, annual mean temperature, and major economic activity, with energy use.

Minerals Yearbook (annual), U.S. Bureau of Mines, Washington, D.C. (Government Printing Office).

Domestic production of the fossil and nuclear fuels by state, national consumption (demand) of fossil and nuclear fuels. Production and consumption of petroleum and coal products. Exports and imports. Prices and transport data. Numbers of active mines and producing oil wells. Labor and productivity data for coal mining. World production of coal, crude oil, and uranium by country.

Energy Statistics (annual), Department of Transportation, Washington, D.C. (Government Printing Office).

Data on transport, production, processing, and consumption of energy. Emphasizes petroleum. Supplement to an annual summary of national transportation statistics.

Outer Continental Shelf Statistics (annual), U.S. Geological Survey, Reston, VA 22092.

Exploration, leasing, drilling, production, and income from oil, gas, sulfur, and salt exploitation on Outer Continental Shelf lands.

Minerals and Materials (monthly), U.S. Bureau of Mines, Department of the Interior, Washington, D.C. 20241.

Domestic fossil-fuel production, consumption, imports and exports, inventories, and prices, by month in the current year and by year for the prior decade or more.

Commodity Data Summaries (annual), U.S. Bureau of Mines, Department of the Interior, Washington, D.C. 20241.

Annual summary of the data included in the monthly *Minerals and Materials,* but with the addition of uranium and thorium.

Press release on energy consumption of prior year (annual, about April 1), U.S. Bureau of Mines, Washington, D.C. 20241.

Supply and demand figures, preliminary, for fossil fuels, hydroelectricity, and nuclear power produced and used in the United States during the prior year, as well as final figures for the year before that. Consumption of fuels and electricity in each of the major economic sectors. Contains data that allow one to adjust the totals given to reflect diversion of energy resources to nonenergy uses. Beware of the way hydroelectricity is calculated—as if it were produced from thermal plants.

Monthly Petroleum Statistics Report (monthly), Federal Energy Administration, Washington, D.C. (National Technical Information Service).

Production, imports, stocks of crude oil, natural gas liquids, and major petroleum products.

International Petroleum Encyclopedia (annual), The Petroleum Publishing Co., Box 1260, Tulsa, OK 74101.

Worldwide and national summaries of oil and gas production and reserves, refining capacity and pipelines. Excellent regional maps show fields, pipelines, refineries, and tanker terminals. Lists of major fields, offshore rigs, enhanced-recovery projects, refineries, tank-

ers, marine construction facilities, computer control projects. Major companies and government agencies concerned with petroleum.

Oil and Gas Journal (weekly), The Petroleum Publishing Co., Box 1260, Tulsa, OK 74101.

The last number of the year contains a global summary of world oil and gas production and reserves, as well as refinery outputs, by country. Oil production is given also by major fields, for each of which the number of wells active and shut-in are listed. Other issues during the year update this information. In addition, there are annual summaries of the world's refineries, offshore facilities, and petrochemical plants. Each weekly issue has a tabulation of gasoline pump prices by state, as well as spot prices for fuel oil; also weekly data on oil imports.

Joint Association Survey of the U.S. Oil and Gas Producing Industry (annual), American Petroleum Institute, Independent Petroleum Association of America, Mid-Continent Oil and Gas Association. Available from American Petroleum Institute, 2101 L St., N.W., Washington, D.C. 20037.

Drilling costs of oil wells, gas wells, and dry holes by state (within Texas, by district) and by depth intervals. Expenditures for exploration, development, and production.

Basic Petroleum Data Book (loose-leaf with annual updates), American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037.

World production of crude oil and natural gas by area. National production by state. Gasoline and fuel oil consumption by state. Data on reserves, drilling finances, prices, refining, imports, transport, and demand. Most tables start with 1947.

Petroleum Market Shares, a Report on Retail Gasoline (monthly), Federal Energy Administration, Washington, D.C. (National Technical Information Service).

Retail sales and average price of motor gasoline at independent and refiner-operated service stations.

Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas in the United States and Canada as of December 31, 19xx (annual), American Gas Association, American Petroleum Institute, Canadian Petroleum Association. Available from American Petroleum Institute, 2101 L St., N.W., Washington, D.C. 20037.

Historical record of production and proved reserves of crude oil, as well as of ultimate recovery and oil-in-place by year of discovery for each state and Texas districts. Annual estimates of proved reserves of natural gas and natural gas liquids, as well as ultimate recovery by year of discovery. The ultimate-recovery series of annual estimates are useful in an exploitation-history approach to depletion forecasting.

Useful to the student of petroleum statistics are two reports of the American Petroleum Institute:

> Technical Report No. 1, *Standard Definitions for Petroleum Statistics* (2d ed.)
>
> Technical Report No. 2, *Organization and Definitions for the Estimation of Reserves and Productive Capacity of Crude Oil* (2d ed.).

Potential Supply of Natural Gas in the United States (irregular), Potential Gas Agency, Colorado School of Mines, Golden, CO 80401.

Latest report is as of December 31, 1976. Estimates by the Potential Gas Committee, a voluntary group, do not include proved reserves but deal only with three categories of potential reserves: probable, possible, and speculative.

Historical Statistics of the Electric Utility Industry (loose-leaf, annual updates), Edison Electrical Institute, 90 Park Avenue, New York, NY 10016.

Generation and sales of electricity in the United States. Data on customers, revenues, and financing of utility industry. Fuel use, cost, and efficiency data for power plants.

Nuclear Power Reactors in the U.S. (quarterly), United States Energy Research and Development Administration**, Washington, D.C. 20545.

Press release on number and generating capacity of commercial nuclear reactor units operable, being built, or planned; map showing locations; listing of plants, unit capacities, and dates of initial commercial operation.

Nuclear Reactors Built, Being Built, or Planned in the U.S. (semiannual), United States Energy Research and Development Administration**, Washington, D.C. 20545.

Lists all reactors: civilian power, experimental, and research, production; military; reactors for export; critical assembly facilities.

Operating History: U.S. Central Power Station Nuclear Power Reactors (annual), United States Energy Research and Development Administration**, Washington, D.C. 20545.

Hours operated, electricity generated, and capacity utilization during year of record and preceding fifteen or so years.

Typical Electrical Bills (annual), Federal Power Commission***, Washington, D.C. 20426.

Report on typical monthly electric bills, showing rates charged for residential service in towns of more than 2,500 inhabitants, and for commercial and industrial services in cities of more than 50,000 inhabitants.

Statistical Data of the Uranium Industry (annual), Grand Junction Office, United States Energy Research and Development Administration**. Available from Bendix Field Engineering Corporation, P.O. Box 1569, Grand Junction, CO 81501.

Uranium ore reserves and production. Potential (un-

** On October 1, 1977, became part of Department of Energy.

*** On October 1, 1977, became part of Federal Energy Regulatory Commission.

discovered) resource estimates. Government ore and concentrate purchases. Distribution of reserves by estimated cost categories. Drilling statistics and exploration expenditures.

International Coal Trade (monthly), U.S. Bureau of Mines, Washington, D.C. 20241.

Reports on coal production, trade, and consumption for U.S. and 10-12 other countries.

Coal Data (annual), National Coal Association, 1130 17th St., N.W., Washington, D.C. 20036.

Statistics on production, preparation, consumption, stocks, distribution, mining equipment, safety, class and manner of shipment, reserves, and so forth. Compiled from government reports.

Coal Facts (biennial), National Coal Association, 1130 17th St., N.W., Washington, D.C. 20036.

Booklet with tables describing the bituminous coal industry and coal's importance to U.S. economy. Text and statistical index cover coal and energy production, transportation, environment, research, NCA operation, markets, reserves, and manpower and safety.

Mineral Facts and Problems (quinquennial, latest is Bulletin 667, 1976), U.S. Bureau of Mines, Department of the Interior, Washington, D.C. (Government Printing Office).

Summary information on fossil and nuclear fuels: industry structure, reserves and resources, technology, byproducts and coproducts, strategic considerations, economic factors and problems, operating factors and restraints, supply-demand relations, and outlook.

FPC News (weekly), Federal Power Commission***, Washington, D.C. 20426.

Contains selected quarterly, monthly, and annual electric power and natural gas statistics.

Gas Facts (annual), American Gas Association, 1515 Wilson Boulevard, Arlington, VA 22209.

Reserves, production, prices, transmission, distribution, and underground storage. Industry customers, sales of gas appliances, revenues, finances, and labor force.

The Oil Producing Industry in your State (annual), Independent Petroleum Association of America, 1101 16th St., N.W., Washington, D.C. 20036.

For each state, the following information is included: number of counties with oil and/or gas production, land area productive or leased, value at wells of crude oil, natural gas liquids, and natural gas produced during year, number of employees engaged in such production, severance taxes paid in year, number of producing wells, average daily production per well, production and new reserves found during year, wells and footage drilled during year.

*** On October 1, 1977, became part of Federal Energy Regulatory Commission.

Hydroelectric Power Resources of the United States (quadrennial), Federal Power Commission***, Washington, D.C. (Government Printing Office).

Data on developed projects, undeveloped sites, trends. Development under FPC licenses and federal development. Statistics grouped not only by region and states, but by major drainages and river basins.

Statistics of Energy (1957-1971, single publication). Organisation for Economic Cooperation and Development, Paris, 1973.

In English and French. Production and utilization of coal, coke, petroleum and its products, gas, and electricity, for each member country. Consumption is detailed by sector.

Annual Bulletin of General Energy Statistics for Europe (annual), United Nations, New York.

In English, French, and Russian. Production of energy by form, and balance sheets of individual forms for each European country and the United States.

Annual Statistical Bulletin (annual), Organization of Petroleum Exporting Countries, Vienna.

Comprehensive statistics on OPEC countries, including producing wells, production of natural gas and crude oil, refining, consumption, exports, world trade, tanker fleets, pipelines, posted prices and retail prices, oil revenues, financial situations of major oil companies.

Highway Statistics (annual), Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. (Government Printing Office).

Data on motor-fuel consumption rates and revenues; vehicle registration, licenses, travel characteristics; federal fuel and automotive taxes; the highway trust fund and highway finance; mileage of public roads and streets.

Automobile Facts & Figures (annual), Motor Vehicle Manufacturers Association of the United States, Inc., 320 New Center Building, Detroit, MI 48202.

Production and registration of vehicles in the U.S., car use, highway mileage, motor vehicle travel, highway fatality rates. World motor vehicle registration, by countries.

Summary Petroleum and Selected Mineral Statistics for 120 Countries, Including Offshore Areas (single publication), Professional Paper 817 (1973), U.S. Geological Survey, Washington, D.C. (Government Printing Office).

Onshore and offshore production and reserves statistics for oil and natural gas.

Coal Resources of the United States, January 1, 1974 (single publication). Bulletin 1412 (1975), U.S. Geological Survey, Washington, D.C. (Government Printing Office).

*** On October 1, 1977, became part of Federal Energy Regulatory Commission.

Reserves and resources, by rank, state, and major beds.

Assessment of Geothermal Resources of the United States—1975 (single publication), Circular 726 (1975), U.S. Geological Survey, Washington, D.C. 20242.

Magnitude, distribution, recoverability of various categories of geothermal resources.

Geological Estimates of Undiscovered Oil and Gas Resources in the United States (single publication), Circular 725 (1975), U.S. Geological Survey, Reston, VA 22092.

Estimates given for a range of probability of discovery and utilization, from ninety-five to five percent. Method of estimation is described.

Air Quality Data (quarterly), Environmental Protection Agency, Washington, D.C. 20460.

Ambient air quality data, organized for each pollutant by sampling site, city or county, Air Quality Control Region, and by state, for various sampling methods.

Radiological Quality of the Environment (annual), Environmental Protection Agency, Washington, D.C. 20460.

Radiation levels in the environment attributable to natural, industrial, commercial, medical, and military sources.

Radioactive Materials Released from Nuclear Power Plants (annual), Nuclear Regulatory Commission, Washington, D.C. 20555.

Radioactive content of airborne and liquid effluents and solid wastes from commercial nuclear power plants.

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